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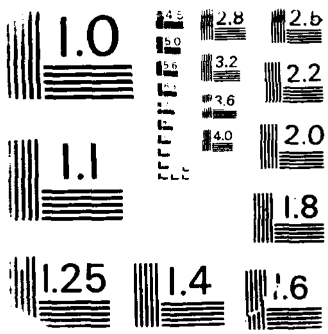
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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

CONTEMPORARY RADAR

by

G. A. Smirnov, V. I. Panov

FOREIGN TECHNOLOGY DIVISION

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

CONTEMPORARY RADAR.

G. A. Smirnov, V. I. Panov.

Candidates in Technical Sciences.

Issue I.

Page 2.

In the pamphlet it is told about the contemporary state and the prospects for the development of radar, are given characteristics and the principle of the operation of radars is described. Is given description of radar [RLS] with the compression of the impulses/momenta/pulses, monopulse and with the phased antenna arrays and also laser locators; it is told about the electronic shf-instruments, used in the radar.

Pamphlet is designed for the wide circle of the readers.

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In our time is difficult to name/call any region of the national economy, wherever radio-electronic technology was not applied. The scientific investigations of different processes are conducted with its aid; it occupies the leading place in the the aircraft- and the navigation. Only because of the high level of the development of electronics it was possible to carry out successful starting/launching of artificial Earth satellites and flights of the manned spacecraft. Radio electronics extensively is used also in the armed forces (Army, Aviation and the Navy), which stand on the guard of the peaceful labor/work of our country.

Radar is one of the most important directions of radio electronics. By term "radar" is understood the area of science and technology, which studies the methods of position finding of different objects with the aid of the radio; respectively the equipment, used for the radio detection, is called "radar technology", "radar stations" (RLS) or simply "radars".

From the moment/torque of the discovery/opening the fundamental principle of radar - the reflection of electromagnetic waves from the obstructions, which are encountered during their propagation, radar

technology passed the complicated way of its development. Different methods of radio direction finding were developed, the velocity of propagation of radio waves was determined, were created theory and of generation, radiation/emission and reception/procedure technique of electromagnetic energy, and also the effective methods of processing radar information. The progress in the region of radar made it possible to carry out gradual transition from the simplest radio engineering devices/equipment, such as were the first samples/specimens of radars, to the contemporary ones, to very complex according to their structure, radar systems, in which is included the whole complex of electronic equipment of different designation/purpose.

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Together with such classical devices/equipment as receivers, transmitters and antenna, in contemporary radars are included the complicated devices/equipment of working/treatment and representation/transformation of radar information. In a number of cases are utilized electronic computers, which make it possible to carry out the programmed control of operation of radars and to process received signals and thereby to considerably improve their characteristics. And although scientific and technical achievements in the region of radar are extremely great, contemporary radar

technology thus far yet cannot accomplish, all, presented to it, requirements. Therefore at present continue both the theoretical and experimental studies, directed toward further improvement in the characteristics of radars.

The electronic methods of scanning ray/beam were developed as a result of these investigations, which made it possible to substantially increase the speed of the survey/coverage of space; were created antennas of the type of the phased grating, which in combination with the programmed control of radiation pattern provide high informativeness and polyfunctionality of RLS; are developed methods and is created the compression technique of impulses/momenta/pulses, that made it possible to sharply raise range resolution without the contraction of radar range; the principles of the construction of radars with the noise sounding signal, which are characterized by high freedom from interference, etc are developed.

In recent years were outlined virgin soil direction in the development of locating technology, foreseen use of an optical (light) wave band. The major advantages of the locators of optical range - possibility of obtaining the highly directional radiations/emissions with the low sizes/dimensions of antenna systems and the absence of the mutual effect of locators with their work in immediate proximity of each other. All new directions indicated in the development of radar are illuminated in the pamphlet, to what extent its space allowed.

Page 5.

Introduction.

Beginning to the development of radar was established by the invention of radio by our great compatriot A. S. Popov. The date of the invention of radio it is accepted to count 7 May, 1895, when A. S. Popov in the report at the conference of the physical separation/department of Russian physicochemical society represented the schematic of his "instrument for detection-electrical oscillations/vibrations" and publicly demonstrated it in action. But in the spring of 1897, continuing experiments on the realization of the "signalings" at a distance, which were conducted in the Kronstadt harbor, A. S. Popov revealed/detected new phenomenon. He noted that when between the cruiser "Africa" and the transport "Europe", isolated for conducting of experiments, fell the third ship, the connection/communication between the first two ships ceased. It was noted, in particular in the report about the results of experiments together with others very interesting data, that the effect of intermediate vessel was observed also. Thus, "during experiments between "Europe" and "Africa" fell cruiser "Lieutenant Il'in", and if this occurred at large distances, then interaction of instruments ceased, until vessels converged from one straight line". This fact,

fixed by A. S. Popov, served as the first in the world observation of the reflection of electromagnetic energy from the obstructions, which are located on the path of its propagation. And this was the greatest discovery, which subsequently became the basis of radar. Unfortunately, the very low level of development of technology in tsarist Russia did not make possible to sweep serious research work in the new region. Only in the years of the Soviet regime because of the personal initiative and the unrelenting concern of V. I. Lenin were widely expanded/scanned research works in the region of radio engineering and radio electronics, which in the future served as the bed, on which was developed the radar.

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The first most serious investigations were conducted in the thirties. By Soviet scientists and by engineers they were proposed, developed and virtually realized the methods of continuous and pulse radiation/emission. Thus, into 1932-1933 by the group of Soviet scientists under the management/manual of academicians N. D. Papaleksi and L. I. Mandel'shtam were proposed and partially realized the methods of radar with the use of continuous radiation/emission of electromagnetic energy. In 1934 P. K. Oshchepkov initiated the development of the pulse method of radar, while in 1937 P. A. Pogorelko, Yu. B. Kobzarev and N. Ya. Chernetsov designed first in

the Soviet Union pulse aircraft detection radar, which for those times had very high characteristics: the maximum detectable range 110-130 km, range accuracy ±(1-2 km) and azimuth ±(2-3°).

The especially rapid development of radar technology was observed into the fiftieth - Sixties. By this time appeared the new types of the generators of the electromagnetic energy, capable of working in different wave bands. Together with the magnetrons as the sources of shf-energy began extensively to be used the klystrons, amplitrons, carcinotrons and other shf-instruments. The pulse power of generators achieved several megawatts at the average/mean power several kilowatts.

With the technology of generation were simultaneously created the new electron tubes and the semiconductor devices, capable fulfill the most diverse functions, such as the transformation of signals. their amplification, etc., and also the low-noise travelling-wave tubes, the parametric and paramagnetic (molecular) amplifiers, which made it possible to considerably raise the sensitivity of receivers. In the same period intensely were developed/processed electronic computers, intended for the work in the radar complexes, and also new methods of processing radar information.

The achievements, attained in the region of radio electronics,

made it possible to considerably improve old ones and to create the new principles of the construction of the radar technology, used in the scientific purposes and different branches of national economy. Radar equipment is established/installed on the vessels of marine and river fleet, on the aircraft of civil aviation, is applied in the truck transport, the research laboratories.

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Radars, adjusted on ships and ships of marine fleet, entered into the category of the fundamental navigation equipment, which ensures the safety of floating under the complicated navigational conditions. The fundamental value of radars, used for the purpose of pilotage, consists in the fact that with their aid it is possible rapidly, to accurately and clearly determine directions and distances of the coast and the vessels, which are located in the zone of action of station. Ship's radar are applied also for the ice observations, especially in high latitudes. The most important characteristics of the state of ice - position of edge, a size/dimension of ice field and a quantity of icebergs - with the aid of radars are determined considerably more precisely than visually, even with the sufficiently good visibility. Extremely serious attention is paid to the development of RLS ◌ this designation/purpose.

Large, complicated and important problems are solved with the aid of radars in the region of meteorology. The use/application of RLS in the weather service made it possible to improve the quality of weather forecasting. The short term and prolonged predictions/forecasts, necessary for almost all services, most fully are comprised with the aid of the special meteorological stations, which determine direction and wind velocity, position and the range of thunderstorm fronts, speed and the direction of the displacement/movement of rain clouds. The appearance of hurricanes and typhoons is predicted with the aid of radars; the meteorologists of airports with the high accuracy measure the lower and upper edges of clouds even with the multilayer cloudiness.

Use/application of radar in the airport weather service gives the possibility to in advance come to light/detect/expose the questions extremely important for the airports: the thunderstorm above a given airfield will take place and if it does pass, then for long it will be prolonged, what wind force and precipitation intensity should be expected. Taking into account that during the thunderstorm phenomena wind can achieve storm sizes/dimensions, the knowledge of precise data about the weather conditions, obtained in advance, has enormous value, since this makes it possible prior to the beginning of storm/gale to take the appropriate measures for warning/prevention of unfortunate cases and the natural calamities.

The measurements of speed and wind direction, as is known, are made on the displacement/movement of the sphere, started into airspace. At the close distances and, of course, in the clear weather after the sphere is conducted the visual observation, and the measurement of its displacements/movements is realized by optical instruments. But as soon as sphere it falls into the zone of dense cloud cover, optic/optics becomes powerless, and radar comes in this case to the aid by it.

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Radar, independently of the time of days and year, independently of weather conditions continuously follows the sphere, measuring the parameters of its displacements/movements, on base of which are designed the speed and wind direction. The knowledge of speed and wind direction is very important, especially at the low altitudes and the distances, for the safety of takeoff and landing.

The new region of radar, which obtained the designation of meteor, was conceived in recent years. Its use/application makes it possible not only to detect meteor showers, but also to measure with the high accuracy of the speed of their motion. The orbits of the

motion of meteors are determined with the aid of radars and their accessory/affiliation with the solar system is revealed.

The wide application of radar in the geodesy made it possible to pass to the new method of determining the marks of points on the earth's surface (aerial photo leveling), because of which it was possible to considerably simplify aerial survey works and to accelerate the mapping of the earth's surface. Aerial photography with the use/application of radar almost completely eliminates the carrying out of ground-based geodetic works with many engineering searches, which are characterized by large.complexity and labor expense.

Radars begin to be applied in the highway transport. In particular, radar speedometers for control/checking and traffic control on the highways are created.

Even now radar increasingly more frequently is utilized in conducting of scientific investigations. Miniature radars gradually displace, where this is possible, the optical instruments, which were until recently the only observation facility of different processes while conducting of scientific experiments.

The greatest reaching/achievement of human genius is the

starting/launching of artificial Earth satellites, whose successful flights it is difficult to present without the participation of radars. Flight service of artificial Earth satellites and space manned ships - newest field of application of radar.

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Characteristics of radars.

The fundamental characteristics of radars are: the range, working frequency band, pulse and average/mean power of transmitter, receiver sensitivity, frequency or pulse repetition period, form and pulse duration, range resolution and angular coordinates, interference shielding, operating speed and reliability. Let us examine some of these characteristics.

The radar range is determined by the fundamental equation of the radar:

$$D_{\text{макс}} = \sqrt[4]{\frac{P_{\text{пер}} G_{A}^{2} S_{ц} \lambda^{2}}{64 \pi^{3} P_{\text{пр мин}}}},$$

where $P_{\text{пер}}$ - power of transmitter, G_{A} - antenna gain, $S_{ц}$ -radar cross section, $P_{\text{пр мин}}$ - the threshold sensitivity of receiver, λ - wavelength.

The given formula is valid when one and the same antenna is utilized for reception/procedure and transfer of signals, and the level of interference is reduced to the minimum is determined only by

internally-produced noise of receiver and by noises of the space and thermal radiations/emissions, which affect the antenna of RLS.

Pulse $P_{и}$ and average/mean P_{cp} of the power of the transmitter of radar are determined by relationships/ratios $P_{cp} = K_{s} P_{и}$ or $P_{cp} = P_{и}/\nu$, where $K_{s} = \tau/T$ - duty factor, and ν=T/τ - value, reciprocal to it, called the porosity [should read: on-off time ratio].

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With pulsing of strictly rectangular form pulse power is equal to the maximum power coefficient in the impulse/momentum/pulse; if the shape of pulses differs from rectangular, then pulse power is characterized by average/mean power coefficient for the pulse action time. By average/mean power is understood the power, averaged during the pulse repetition period. For example, at pulse power $P_{и} = 100$ kW, τ=0.5 μs and T=1000 μs average/mean power will be $P_{cp} = 50$ W. The amount of average/mean power will be the less in the case of identical pulse power, the greater the porosity, i.e., the greater the ratio of repetition period to the duration of pulse (Fig. 1). The values of the duty factors and porosity in contemporary radars are within the limits: $K_{s} = 0.02 - 0.005$ and ν=50-2000 respectively.

Pulse power (one of the fundamental parameters, which determine

the radar range) in the latter/last decade in the latter/last decade increased 5-7 times and achieved almost limiting values. However, such levels do not give the possibility to obtain the desired range of action of contemporary RLS, but further increase in the power leads to the breakdowns in the generator and amplifier instruments, the supplies of power and the circuits of the transfer of high-frequency energy. In connection with this new type radars were developed with the use/application of phased antenna arrays (FAR), whose high power levels are formed in the space after the radiation/emission of electromagnetic energy, and therefore the possibility of the breakdowns of radio engineering elements/cells virtually completely is eliminated.

The pulse repetition period T is determined by the range of time from the beginning of the radiation/emission of the subsequent impulse/momentum/pulse preceding/previous to the beginning of radiation/emission (see Fig. 1). The value, reciprocal to repetition period (1/T), it is called repetition frequency and is designated by the letter F.

So that the image of the signals echo from the objects on the scope of radar would be stable, it is necessary to accept 5-10 impulses/momenta/pulses for the time, during which the object is located in the radar beam.

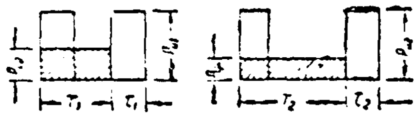

Fig. 1. Pulse, and average/mean power.

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Based on this condition, and also taking into account that the width of radiation pattern and the antenna scan rate are assigned, for determining the repetition frequency it is possible to use formula $F=n\omega/\Theta$, where n - quantity of impulses/momenta/pulses, which ensures a good observability; ω - antenna scan rate, expressed in rad/s; Θ - width of the radiation pattern (beam width) of antenna.

The frequency band of the repetition, utilized in radars, is limited to lower and upper limits: lower repartition/conversion is determined by the properties of human eye, and upper - by maximum radar range. It is known that the eye of man receives light sensations with certain inertness, whose value is approximately/exemplarily 0.1 s (the "time constant" of eye). In order that the image of the echo signal on the scope not flicker, repetition period must be not more than 0.05 s. Thus, the minimum pulse repetition frequency is limited to value $F_{мин} = 1/T_{макс.} = 1/0.05 = 20$

imp./s. The maximum value of repetition frequency is selected from the condition: $F_{макс} \leqslant 0.4\, c/D_{макс}$, where c - velocity of propagation of electromagnetic energy; $D_{макс}$ - maximum radar range.

Contemporary radars have repetition frequencies from 50 to 1000 imp./s: and the values corresponding to them of the pulse repetition period are within the limits from 20000 to 100 μs.

Form and pulse duration have an effect in essence on two indices of radars: the accuracy of ranging and range resolution. Range to the object is determined in the series/row of stations on the position of the initial point of leading impulse front on the scope. If leading edge flat, and on time sweep of indicator act noises, then to determine the position of the initial point of leading edge proves to be difficultly. The error in ranging appears as a result. It is completely obvious that to decrease it is possible by an increase in the slope/transconductance of leading impulse front. However, this requires the expansion of the passband of the frequencies of the receiving channel of RLS, which is connected with the specific technical difficulties, and with the contraction of the range of station.

Impulses/momenta/pulses with the large slope/transconductance of leading edge (form of which is close to the rectangular) are applied

only when the very high accuracy of ranging is required. If stringent requirements for the accuracy it is not presented as, for example, in early-warning radar, transmitted pulses can have trapezoidal, bell-shaped and even triangular form.

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The required passband of the frequencies of the receiving channel is reduced in this case, which, other conditions being equal, increases the radar range.

The duration of pulse - one of the fundamental factors, which determine range resolution, by which is understood the ability of RLS to separately observe the signals, reflected from the objects, arranged/located on one direction. Let us determine resolution on the assumption that the impulse/momentum/pulse has rectangular form. Let two objects A and Б (Fig. 2) be found in the direction of propagation of sounding pulse. Object A is near, while object Б - remote with respect to the station. At certain moment of time the leading edge of sounding pulse will achieve object A, and electromagnetic energy will be reflected from it during the time, equal to the duration of sounding pulse, τ. After time $t=\Delta D/c$ (where ΔD - distance between objects A and Б, c - the velocity of propagation of electromagnetic energy), after the beginning of reflection from object A the leading

edge of sounding pulse will achieve the object Б, from which also will begin to be reflected electromagnetic energy.

It is completely obvious that the signals, reflected from objects A and Б, will be examined/scanned separate on the scope, only in such a case, when reflection from the object A ends somewhat earlier than the signal, reflected from the object Б, will approach it. Thus, for the separate reception of signals must be carried out inequality $2\Delta D/c \geq \tau$, i.e., the time lag of the signal, reflected from the object Б, with respect to the signal, reflected from object A, must be more than the duration of sounding pulse. Hence easily is determined range resolution: $\Delta D_{\text{мин.}} = c\tau/2$.

By the same expression is determined dead range, or the so-called dead zone, radar. Let us substitute the numerical value of the velocity of propagation of electromagnetic energy and let us determine resolution for two values of the duration of pulses $\tau_1 = 1$ μs and $\tau_2 = 0.1$ μs: $\Delta D_{\text{мин}\,1} = c\tau_1/2 = 3 \cdot 10^8 \cdot 1 \cdot 10^{-6}/2 = 300/2 = 150$ m; $\Delta D_{\text{мин.}\,2} = c\tau_2/2 = 3 \cdot 10^8 \cdot 0{,}1 \cdot 10^{-6} = 15$ m. Range resolution, as can be seen from the given examples, it depends only on the pulse duration: the shorter the impulse/momentum/pulse, the higher the resolution.

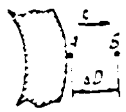

Fig. 2. To the explanation of resolution.

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However, to raise resolution by pulse shortening is not always possible, since it leads to the considerable contraction of radar range. When is required to have high range resolution and simultaneously the long range of the action of station, so-called RLS with the compression of impulses/momenta/pulses are utilized.

Principle of operation RLS measurement of coordinates.

Fundamental problem of radar - detection of targets (aircraft, ships, ground-based points/items, etc.) and the determination of their position (coordinates). The position of ground-based objects is determined by two coordinates - range and azimuth. For determining the position of object it is necessary to know three coordinates: slant range, azimuth and angle of elevation or height/altitude.

The principles of radar are based on the use of four objectively

existing factors.

1. Abilities of electromagnetic energy to be reflected from objects/subjects, which are lo d on path of its propagation (this property it makes it possible to judge presence or absence of object in field of "view" of station).

2. Constancies of veloc ty of propagation of energy (property, which is bed, on which it rests ranging).

3. Concentrated (directed) radiation/emission of energy (it serves as base for measuring angular coordinates).

4. Doppler effect (on its use they are based methods of velocity measurement of motion of objects and their selection against the background of signals, reflected from fixed objects/subjects).

The measurement of coordinates and parameters of the motion of object can it is conducted by both the pulse-modulated radar and by stations, which work in the mode of continuous radiation/emission. For this in their composition there are special blocks and devices/equipment, which fulfill the strictly defined functions. Let us examine briefly composition and designation/purpose of basic building blocks, and also the principle of the operation of radar.

Composition of RLS. Fig. 3 shows the generalized block diagram of radar. From the figure one can see that in the station it is possible to isolate five devices/equipment, which fulfill the most specific functions: antenna feeder system, receiving and transmitting devices, sometimes structurally united into one general/common/total block (transceiver), display unit and synchronizer.

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Furthermore, in any radar compulsorily is included power supply.

Antenna feeder system consists of antenna, antenna switch and feeder lines of transmission of energy, which connect antenna with the receiver and the transmitter.

Antenna switch is applied only in pulsed radars, because in them the functions of reception/procedure and transmission are fulfilled by one antenna. The need for its use/application is explained as follows. Let us assume that the switch is absent. Then receiver and transmitter must be constantly connected to the antenna. But a similar connection of blocks will involve at least two very undesirable phenomena: first, the powerful/thick sounding pulses,

generated by transmitter, will pass into the receiver and will render inoperable (they will destroy) its highly sensitive input circuits; in the second place, the part of the energy of the signal accepted (assuming that the receiver remained intact/uninjured/undamaged) will branch into the transmitter, and therefore the weakened signal will enter to the input of receiver, which will lead to the contraction of radar range.

For preventing the phenomena indicated serves the antenna switch, which presents electronic relay, as which is utilized the gas-filled tube - discharger/gap. With its aid on the period of the radiation/emission of sounding pulse the antenna automatically is disconnected from the input of receiver and is connected with the output of transmitter. To the period of the pause between transmitted pulses, on the contrary, the antenna is disconnected from the output of transmitter and is connected with the input of receiver how are reached the necessary conditions for the reception of signal, reflected from the observed object.

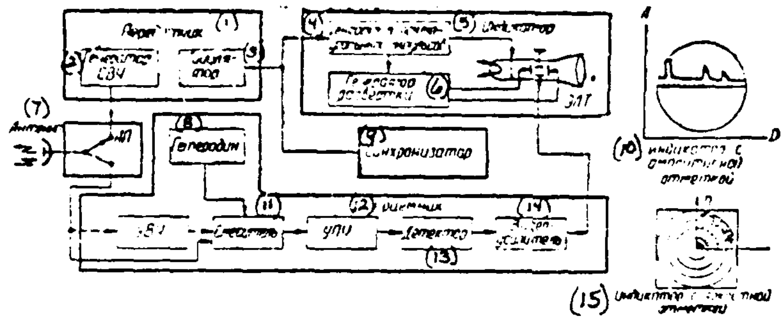

Fig. 3. Generalized functional diagram of radar.

Key: (1). Transmitter. (2). Generator of shf. (3). Modulator. (4). Square-wave generator. (5). Indicator. (6). Generator of sweep. (7). Antenna. (8). Heterodyne. (9). Synchronizer. (10). Variable-displacement indicator. (11). Mixer. (12). Receiver. (13). Detector. (14). Video amplifier. (15). Indicator with brightness mark.

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In radars with the continuous radiation/emission the reception/procedure and transmission are realized by separate antennas, and therefore the requirement for the antenna switch drops off in them.

Feeder system serves for the transfer of high-frequency energy

from the generator to the antenna and from the antenna to the receiver. In radars of meter and partly decimeter of ranges as the feeder lines are utilized flexible coaxial cables, while in RLS of centimeter band - waveguides and sometimes rigid coaxial lines.

Transmitter consists of the generator of shf-energy and modulator. The sounding pulses (assigned duration), emitted by antenna into the space, are developed by it.

Special high-frequency tubes are utilized in radars of meter and decimeter wave bands as the generators of transmitters. In the transmitters of RLS of centimeter and the adjacent it part of the decimeter of ranges the widest application obtained magnetrons and klystrons.

Modulator in the general case serves for imparting to the high-frequency sounding signals the specific "coloration", and in the pulse stations and for the accumulation of energy. For the radar are characteristic three forms of modulation: pulse (variety of amplitude), phase and frequency. Latter/last two forms are applied in radars with the continuous radiation/emission.

Let us pause at some special features/peculiarities of the modulator of pulse-modulated RLS. For the time of the

radiation/emission of impulse/momentum/pulse the transmitter of station expends/consumes extremely large power, whose value in different destinations can reach hundred and even thousands of kilowatts. The consumption of this power from the power supply would directly create unfavorable working conditions both for the source itself and for radar as a whole and, furthermore, it would lead to the considerable complication of the construction/design of the supply of power, transmitter and other blocks. In order to avoid this, the modulators, that have the special elements/cells, capable of accumulating electrical energy, are applied in pulse-modulated RLS. The functions of the accumulators/storage of energy can fulfill capacitors, inductance coils and artificial lines formed from the series-connected cells, which consist of capacitors and inductance coils. The accumulation of energy occurs for the time of the pause between the impulses/momenta/pulses. The parameters of storage elements are selected in such a way that the energy stored in the modulator would be sufficient for exciting of generator and maintenance in it of high-frequency oscillations during the radiation/emission of the powerful/thick sounding pulse.

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Receiver consists of the high-frequency amplifier, mixer, heterodyne, intermediate-frequency amplifier, detector and video

amplifier. The devices/equipment of the automatic gain control (ARU) and automatic frequency control (APCh) can be also in its composition. Fundamental functions, performed by the receiver: the isolation/liberation of useful signal from the entire totality of the electromagnetic vibrations, taken by antenna, its transformation into the signal of the lower, so-called intermediate, frequency, the amplification and the detection or the isolation/liberation of the envelope of radio-frequency signal.

Indicator is intended for the observation of the objects and measuring their coordinates. Electrical circuit, type and construction/design of indicator are determined by the designation/purpose of radar. The cathode-ray tube (CRT) is utilized as the instrument for the representation/transformation and the observation of radar signals.

Synchronizer is intended for the control of operation of entire radar. It is given the required pulse repetition frequency and realizes agreement on time (synchronization) of the work of transmitter, receiver and display unit. The multivibrator usually is utilized as the synchronizer. Structurally it can be carried out in the form of independent block or enter by component part into the indicator or transmitter of station. The synchronizer can generally be absent in the simplest versions of RLS. In such cases the

repetition frequency is assigned directly by modulator.

The principle of operation of RLS. Thus, in the gap/interval between the synchronizing pulses energy in the elements/cells of modulator is accumulated, they are charged from the power supply. So that the storage element would be charged gradually, and also that it would not appear the large circuital currents of charge during the generation of sounding pulses (i.e. for the protection of power supply from the overloading), in the circuit of charge is included any limiting element/cell - effective resistance, or inductance.

With the arrival of synchronizing pulse occurs the discharge of the storage element. The voltage/stress, which is isolated on the load of modulator, is applied to the electrodes of oscillator tube, moreover it proves to be sufficient for its excitation and maintaining the process of the generation of high-frequency oscillations. The sounding pulse, developed by generator, through the antenna switch enters antenna and is emitted into the space.

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The duration of the generatable pulse is determined by the parameters of modulator (in particular, by the time constant of the discharge circuit of the accumulator/storage of energy), and repetition

frequency strictly corresponds to pulse repetition rate, developed by synchronizer.

The generation ceases after the radiation/emission of sounding pulse, and again occurs the accumulation of energy in the elements/cells of modulator.

The signal, emitted by antenna, reaches object, it is reflected from it and it begins to be propagated in the opposite direction. By this time antenna with the aid of the antenna switch proves to be connected to the receiver of RLS. In radars of meter range the signal accepted is amplified in the high frequency for the purpose of an improvement in the signal-to-noise ratio and is supplied to the mixer. In RLS of centimeter band the amplification in the high frequency on is applied, because in this range of tube they have high inherent noise level and possess low amplification factor, in view of which they become barely effective. Therefore in the stations of centimeter band the signals accepted from the antenna are supplied directly to the mixer. Let us designate their frequency through f_c. The signals of heterodyne with a frequency of f_r here are fed/conducted. Intermediate frequency f_n is formed as a result of their interaction. Depending on that, which of the frequencies is more, f_c or f_r, intermediate frequency will be determined by appropriate expression $f_n=f_c-f_r$ or $f_n=f_r-f_c$.

The converted radio-frequency impulse/momentum/pulse is amplified in the intermediate frequency and is supplied to the detector, with the aid of which is isolated its envelope. The detected impulse/momentum/pulse is called video pulse. Stress level on the output of detector, as a rule, is very low. It is only the portions of volt, and for the normal work of cathode-ray tube it is necessary to have several ten volts. Therefore video signal is amplified in the receiver to the necessary level, and then is supplied into the display unit.

Simultaneously with the starting/launching of modulator (by beginning of the radiation/emission of sounding pulse) synchronizer starts the voltage generator of scanning/sweep in the display unit, which develops saw-tooth voltage. It is applied to the horizontal deflectors of cathode-ray tube it is utilized for the displacement of focus (formed by electron beam of CRT) in the horizontal direction. Rate of voltage rise is selected taking into account that so that the focus would finish its path on the screen/shield somewhat later than the moment/torque of the arrival of impulse/momentum/pulse, reflected from the object, which is located on the maximum range of station.

After passage by the ray/beam of entire screen/shield the sweep voltage drops to zero and ray/beam returns to initial position. The new cycle of its motion will be begun with the arrival of the following timing pulse.

Thus, at the moment of radiating/emitting each sounding pulse and scope are formed the glowing line, "traced" from left to right. It is called sweep trace. Upon the return of ray/beam to initial position can appear the same line, but "traced" from right to left. In order to avoid this, by the return period sharply it decreases image brightness of indicator, for which to control electrode of tube the square pulse of negative polarity, developed by the special generator of cutoff voltage, is supplied.

The video pulse, which enters from the receiver the indicator, is fed/conducted to the vertical deflectors of tube. As a result of its action the electron beam obtains vertical deflection, forming on the sweep trace the sharp oversnoot, on which is fixed/recorded the presence of the signal echo from the object. At the termination of the action of video pulse the ray/beam returns to the sweep trace and motion in the horizontal direction is continued until the following impulse/momentum/pulse, reflected from the more distant object,

enters.

Thus, we examined operation of radar, in which was accepted the indicator with the linear scanning/sweep and the amplitude method of indication. Only the method of indication will change with the use/application of other types of indicators (for example, with the brightness mark). The principle of operation of RLS as a whole will be preserved by previous.

Ranging, as has already been indicated earlier, possibly because of the fact that electromagnetic energy is propagated with the constant velocity. In the contemporary radar the range can be measured by several methods. Their number includes pulse, frequency and phase. The method of measurement, based on the use of the Doppler effect, sometimes is applied. Only the pulse method, which obtained the widest acceptance, will be here examined; with the rest the reader can in detail become acquainted in the book of A. P. Sivers et al. "Principles of radar" (L., 1959).

Pulse method is based on the measurement of the total time, for which the impulse/momentum/pulse passes path to the object and vice versa. Let us examine how it is realized virtually. Let us recall for this that with the radiation/emission of sounding pulse by synchronizer is simultaneously started scanning/sweep of display

unit. Let the horizontal size/dimension of scope be equal, for example, to d=20 cm, and the development/scanning ray/beam on the screen/shield is realized in 2 ms; then each centimeter of path on the screen/shield will pass ray/beam for the time t=2:20=0.1 ms.

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Further let us assume that the signal, reflected from the object and accepted by station, is observed at point, which is located at a distance of 5 cm from the beginning of sweep trace. Since ray/beam in the process of development/scanning moves along the scope with constant speed, then it will prove to be at the point (under the conditions stipulated above) indicated through 0.5 ms. This means that the emitted by station impulse/momentum/pulse covered a distance of the object and vice versa also within the time t=0.5 ms.

Knowing this time and velocity of propagation of electromagnetic energy (it is equal to $c=3\cdot10^5$ km/s), range can be calculated according to the known from physics formula $D={}^1/_2ct$, where: D - range, km; t - time, s. Introduction to the formula of coefficient ${}^1/_2$ is caused by the fact that in time interval, measured by radar, the impulse/momentum/pulse passes the distance, equal to the doubled range, "there" and "conversely". After substituting into the formula of the value of speed c and measured time t, we will obtain range. In

the example examined it is equal to $D={}^1/_2\cdot3\cdot10^5\cdot0.5\cdot10^{-3}=75$ km. Range scale is calibrated directly in ones the measurement of distance taking into account coefficient ${}^1/_2$.

Velocity measurement. The radar method of velocity measurement of the motion of objects is based on the use of the Doppler effect, whose manifestation for the reader, obviously, was necessary repeatedly to perceive, when it was located on the platform of railway station. However, the classical example, which elucidates, is renewed again in the memory, to what result it leads this effect. Let us recall that the tone of the signal whistle of the approaching a station train is raised. However, what does serve as a reason this? The fact is that with the approximation/approach of sound source to an observer occurs the "incidence" (shortening) of acoustic wave (increase in the frequency). This phenomenon leads to an increase in the tone. During the removal/distance of sound source, on the contrary, occurs the "distention" (elongation) of wave (decrease of frequency), and therefore decrease in the tone is perceived. Thus, the Doppler effect appears in a change in the frequency of sound vibrations during the motion of sound source relative to observer. A similar phenomenon exists also in the radar. The increment in the frequency, obtained as a result of the displacement of the irradiated object relative to RLS, is called Doppler frequency and is designated by symbol $F_{д}$.

It follows from the example examined that in the case of approaching the driver to an observer the frequency of received signal will be equal to $f_1=f_0+F_д$, and during the removal/distance - $f_2=f_0-F_д$, where f_0 - signal frequency, emitted by source.

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In connection with radar Doppler frequency can be expressed through the velocity of propagation of the electromagnetic energy c and the speed of motion v of the object, observed by radar: $F_д=[2v/(c-v)]\cdot f_0$. Taking into account that c>>v, the expression for determination $F_д$ can be recorded in the simpler form: $F_д\approx (2v/c)\cdot f_0$. If, for example, object approaches radar with a velocity of v=300 m/s, and signal frequency, emitted by RLS, f_0=200 MHz, then $F_д=(2\cdot 300/3\cdot 10^8)\cdot 200\cdot 10^6=400$ Hz.

Doppler frequency and speed of the motion of object are found in the direct proportional dependence. This means that a decrease or an increase in the speed in n of times will cause respectively a decrease or an increase of Doppler frequency also in n of times.

Analyzing the expression, which determines F_d, it is not difficult to be convinced of the fact that it makes it possible to solve inverse problem, i.e., to determine the speed of the motion of object in known carrier frequency f_0 and measured Doppler frequency F_d: $v = (c/2f_0) \cdot F_d$. For measurement F_d usually is utilized the frequency meter, which presents the system of the narrow-band filters, whose operating frequencies are previously known. The scale of frequency meter can be calibrated completely directly in the units of speed.

Measurement of angular coordinates. The determination of direction to the object with the aid of the radio equipment is called radio direction finding. There are several methods of measuring the angular coordinates. Let us examine some of them.

The method of maximum (Fig. 4a) is based on the determination of antenna position at that moment/torque, when the greatest amplitude (or the most intense brightness mark) of the signal, reflected from the object, is examined/scanned on the scope of radar. This position is observed each time, when the axis of the ray/beam, formed/shaped with antenna, coincides with the direction to the object. Fundamental advantage of the method of maximum - simplicity of the determination of direction and the high value of signal-to-noise ratio. Its deficiency/lack - low accuracy of measurement due to too flat a form of radiation pattern. Therefore the method of maximum mainly is

applied in early-warning radar, where the high accuracy of measurements is not necessary.

The method of the minimum (Fig. 4b) requires the use/application of antenna systems, capable of forming/shaping two-lobe radiation pattern. The reading of the measured angle is conducted on the minimum level of the signal accepted, when object is found on the line of zero radiation/emission.

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Theoretically the accuracy of measurement could be very high, since in the ideal case (in the absence of the inherent noise of receiver) even very insignificant divergences of object to that or other side from the line of zero radiation/emission would give comparatively large changes in the level of received signal. However, to in practice realize high accuracy is impossible. As reason this it serves from the fact that in the specific interval of the angles, to which is displaced the observed object from the zero line, the level of the useful signal, accepted by RLS, proves to be so it is low that it is almost completely masked with the inherent noise of receiver and does not make it possible to carry out measurements. A confident reading of the measured angle can be made only when useful signal on its level is more than receiver noise and clearly it is isolated on

the scope.

The reasons examined and the series/row of other special features/peculiarities, characteristic to the method of the minimum, lead to the fact that the accuracy of the measurement of angular coordinates proves to be commensurable with the accuracy, which is obtained in the measurement on the maximum, signal.

Method of comparison (Fig. 4c) is based on the use of two diagrams, which partially overlap each other. Its essence lies in the fact that the direction to the object is determined via the comparison of the amplitudes, accepted by each diagram. The reading of the measured angle is conducted with the equality of amplitudes of both signals, and it, as may be seen from the figure, it can be only in such a case, when object is located at point A, on the so-called equisignal direction (line OA). When object is displaced (for example, into point C), the level of the signal, accepted by the first diagram, is lower than the level of the signal, accepted by the second diagram. A difference in the amplitudes is proportional to angle of deflection θ. In tracking radar differential signal is converted into the voltage/stress, called the signal of angular error. It characterizes the amount of deflection of object from the line of equisignal direction to the right or to the left and is utilized in the final analysis for the control of antenna.

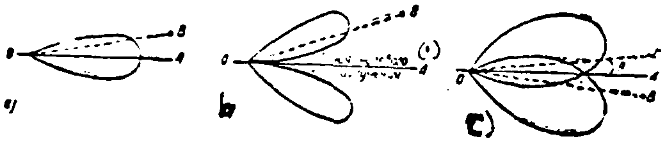

Fig. 4. Determination of the angular coordinates: a) the method of maximum; b) the method of the minimum; c) comparison method.

Key: (1). Line of zero radiation/emission.

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The mechanisms, on which acts the voltage/stress of angular error, attempt to hold down/retain antenna in this position that the accompanied object always would be found on the line of equisignal direction.

For measuring the angle by equisignal method of one plane the antenna, which forms radiation pattern, can consist, for example, of two horns, which alternately irradiate one mirror. If the measurement of angular coordinates must is made in two planes, then will be required four horns (two in each plane), that train also one mirror. During the successive irradiation the mirrors by the appropriate horns of radiation pattern will be deflected to the left - to the

right and upward - down.

The method of determining the angular coordinates examined is occasionally referred to as the method of consecutive lobe switching of directivity.

The method of the conical scanning of ray/beam, used also in tracking radar, is its logical continuation. It differs from that previously examined there, that during the conical scanning the radiation pattern continuously rotates around the line of equisignal direction, which coincides with the centerline of antenna. In this case the signals, reflected from the object, are modulated in the amplitude with the frequency, equal to the frequency of the rotation of diagram (to frequency of scanning). The depth of modulation in essence depends on the divergence of object from the line of equisignal direction. If object is found on the equisignal line, then the signals echo from it have constant amplitude. As in the previously method examined, the voltages/stresses of angular errors, developed during the conical scanning from the amplitude-modulated signals, are utilized for the control of antenna and the coincidence of its optical axis with the direction to the accompanied object.

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RADAR WITH THE COMPRESSION OF PULSES.

The requirements of the large radar range and high range resolution are contradictory. Therefore a question about their fulfillment was until recently solved by the compromise path: large radar range was reached due to certain deterioration in the resolution, and the high resolution due to the contraction of the range of station. The contradiction indicated is not by chance. It is explained by the fact that the resolution can be raised only via the shortening of sounding pulses, and this, as is known, with the retention/preservation/maintaining of other parameters it leads to the decrease of average/mean power and, as a result, to the contraction of the radar range.

Let us give the example confirming this confirmation. From the formula, which determines the dependence of pulse and average/mean power, it follows that with the shortening of the pulse and average/mean power, it follows that with pulse shortening, for

example, 10 times the average/mean power of transmitter (at the same value $P_{и}$) decreases also 10 times. As a result, as can be seen from the fundamental equation of radar, the range of station will be shortened in $\sqrt[4]{10}=1.8$ the time. In order to preserve the initially assigned range with pulse shortening indicated, it is necessary to increase pulse power up to such level, on which its average/mean value during the repetition period will achieve previous value. However, excessive increase in $P_{и}$, as has already been indicated, can cause the breakdowns of radio engineering elements/cells or will be necessary the considerable complication of the construction/design of generator, as a result of which the sizes/dimensions and the weight of transmitter can substantially increase. But this is not always admissible.

In order to preserve the power, sufficient for achievement of the required range, and at the same time to raise resolution, was developed the method of the "compression" of impulses/momenta/pulses, which extensively is used in contemporary radars.

They sometimes assume that RLS with the compression of impulses/momenta/pulses represents device/equipment with the operating principles, radically by different ones from those, which are utilized in the usual pulse-modulated radar. A similar representation is erroneous. Any actually existing radar, which works by long impulses/momenta/pulses, for increasing the resolution can be

supplemented by the special devices/equipment, which ensure their compression.

Fig. 5 shows the block diagram of this station. It differs from the diagram of usual pulse-modulated RLS only in terms of the presence of the frequency shift key in the transmitter and the filter, compressive impulses/momenta/pulses, in the receiving channel (emitted and taken signals for the clarity they are depicted in the form of video pulses, actually they they are radio pulses). The principle of operation of RLS with the compression is almost completely analogous to the principle of the operation of usual pulse station. Difference consists only of the fact that in radars with the compression of impulses/momenta/pulses the sounding signal is modulated in the frequency, and echo from the object and accepted by station frequency modulated pulses after conversion and amplification "are pressed" in the time with the aid of the special filter. The resolution of station is determined by the duration of the compressed pulse.

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Let us return again to Fig. 2 and will snow, what picture will be observed on the scope during irradiation of two objects A also Б by long pulses. Let us assume that the detection is conducted by

radar, which has the duration of pulse τ more than time $t=2\cdot\Delta D/c$, for which electromagnetic energy passes path from A to Б and vice versa. With this assumption (if is not applied compression) echo from the objects puls; 1 and 2 will be applied to each other and they will luminesce on the scope in the form of one, increased according to the sizes/dimensions of marker. Their location on the sweep trace is shown in Fig. 6. A similar image, naturally, will not make it possible tc observe objects A and Б separately.

Special treatment of the signals (with the aid of the filter) accepted makes it possible to press impulses/momenta/pulses in the time. Thus far, without going into particulars of what the principle of the compression (it it is examined below), consists, let us point out that in the sense of reaching/achievement of the required resolution the compression of impulses/momenta/pulses, realized in the receiving channel, almost is completely equivalent to the shortening of those sounding by transmitter. The impulses/momenta/pulses, which passed through the compressive filter, in Fig. 6 are designated by numerals 3 and 4. Their alignment on the sweep trace t shows that as a result of pulse compression they prove to be divided by time interval. A similar image of signals on the scope provides clear separate observation of both objects A and Б. In this consists the essence of the use/application of compression of impulses/momenta/pulses for the purpose of an increase in the resolution.

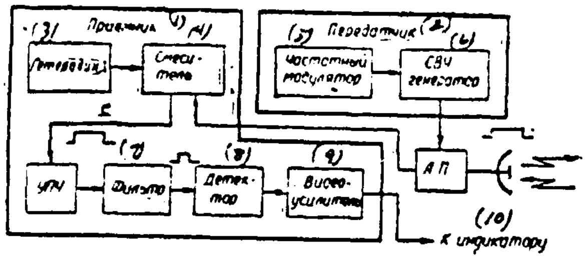

Fig. 5.

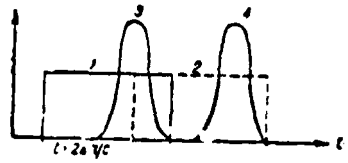

Fig. 6.

Fig. 5. Block diagram pf RLS with compression of impulses/momenta/pulses.

Key: (1). Receiver. (2). Transmitter (3). Heterodyne. (4). Mixer. (5). Frequency shift key. (6). Shf generator. (7). Filter. (8). Detector. (9). Video amplifier. (10). To indicator.

Fig. 6. To explanation of resolution during compression of impulses/momenta/pulses.

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Now let us examine, in what the principle of compression consists and as virtually it is realized. In order to obtain the required range (certainly, at the assigned power of transmitter) and high range resolution, as is known, necessary to attain the high

value of the product of the width of the spectrum of the emitted signal to its duration. This means that the sounding pulse, in the first place, must be long (under this condition the average/mean power of transmitter it proves to be a sufficient for the realization desired radar range)and, in the second place, it must have wide frequency spectrum (condition, equivalent to shortening of the pulse; its fulfillment it makes it possible to raise range resolution).

Simultaneous satisfaction of the conditions indicated is achieved by the use/application of intra-pulse frequency modulation of the sounding signal. It can be realized by active or passive methods. As an example let us examine only the first them them.

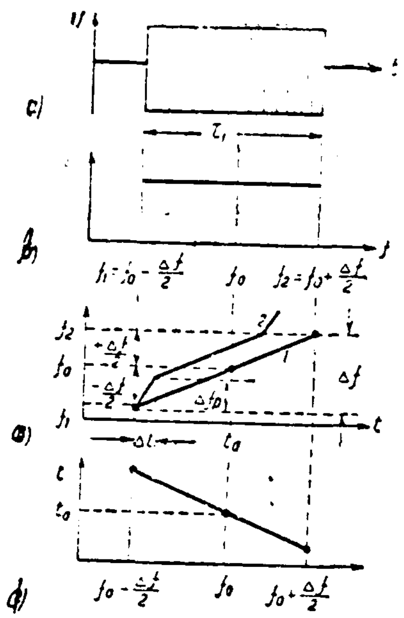

Fig. 7.

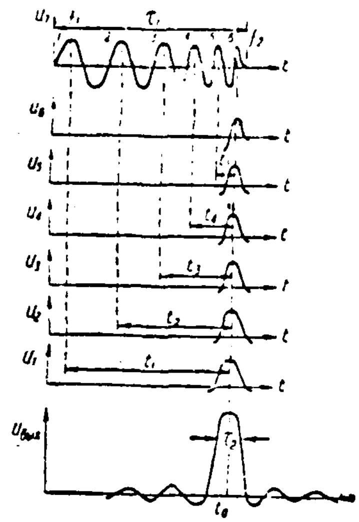

Fig. 8.

Fig. 7. Idealized characteristics of frequency modulated impulse/momentum/pulse and system of compression.

Fig. 8. Compression of impulses/momenta/pulses in matched filter.

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With the active method the signal is modulated directly in the transmitter itself. In this case the transmitter of RLS with the compression of impulses/momenta/pulses differs from the transmitter

of usual pulse-modulated radar only in terms of the presence of the frequency shift key.

Signal carrier frequency (Fig. 7a) with intra-pulse modulation is determined by expression $\omega=\omega_0+(\Delta\omega\cdot\tau_1)\cdot t$ with $|t|<\tau_1/2$, where ω_0 - medium frequency, $\Delta\omega=2\pi\cdot\Delta f$ - circular deviation of frequency, τ_1 - duration of the emitted pulse. If the product of the deviation of frequency to the duration of pulse $\Delta f\cdot\tau_1=(f_2-f_1)\tau_1$ is sufficiently great, then according to linear law the increase of the carrier frequency in the transmitter from f_1 to f_2 (Fig. 7c straight line 1) will give almost rectangular distribution of the spectrum of the amplitudes of the sounding signal (Fig. 7b). The linear law of a change in the frequency makes it possible to use for the compression of impulse/momentum/pulse the special, so-called matched filter, with the aid of which is realized the delay of one pulse edge relative to another. The inclination/slope of delay characteristic of filter (Fig. 7d) must be reverse to the inclination/slope of the straight line, which determines the law of a change in the carrier frequency. This characteristic makes it possible to realize the larger delay time of low-frequency components in the beginning of impulse/momentum/pulse in comparison with the delay time of the high-frequency components at the end of the impulse/momentum/pulse (Fig. 8), that also is required for its compression.

Let us examine the process of compression with the aid of the filter in more detail. For example, delay line with the removals/outlets can serve as a filter. The compression of the frequency modulated impulse/momentum/pulse is based on the delay of separate frequency components to different time intervals. Let us assume for simplicity that the modulated pulse contains six frequency components. Therefore let us divide it into six parts in such a way that one oscillatory period would correspond to each of them. Let us feed the impulse/momentum/pulse in question on the input of filter. In transit through it all parts (frequency components), except the sixth, will be delayed (see Fig. 8): the fifth to period t_5, the fourth - on t_4, the third - on t_3 and so forth. With such delay times all frequency components will prove to be at the output of filter simultaneously t_6. As a result of their summation the impulse/momentum/pulse "is pressed" (pulse-frequency spectrum it is expanded), and pulse power increases.

The duration of the compressed pulse at the level 0.7 is determined by expression $\tau_2=1/\Delta f$, where $\Delta f=f_2-f_1$ - deviation of th carrier frequency. The ratio of the duration of pulse τ_1 at the input of filter [illegible] duration of the compressed pulse τ_2 at its output is called the contraction coefficient, which it is accepted to designate by symbol $K_{c\kappa}$.

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Thus, contraction coefficient is determined by expression $K_{cж} = \tau_1/\tau_2$. The power of the compressed impulse/momentum/pulse increases proportional to contraction coefficient: $P_{вых}/P_{вх} = \tau_1/\tau_2 = K_{cж}$, where $P_{вых}$ — power at the output of filter, $P_{вх}$ — power at its input. The amplitude of output potential of filter increases в $\sqrt{K_{cж}}$ once, i.e., $U_2 = U_1\sqrt{K_{cж}}$, where U_2 and U_1 - output potentials and at the input of filter, respectively.

The virtually matched filter for the compression of impulses/momenta/pulses, as has already been indicated, can be carried out on the electrical delay line with the removals/outlets. In this case the greater the removals/outlets in line, the more contraction coefficient can be realized.

The compressive filters are constructed also on the base of broadband ducts/contours or combined systems, which consist of the electrical lines of delay and band-pass filters. The broadband ducts/contours, as fundamental elements/cells of which serve inductance coils and capacitors, make it possible to obtain contraction coefficient not more than 500, but the combined systems - 10^3-10^4.

Filters on the electrical delay lines are usually complicated

and bulky and therefore they did not have extensive application.

The at present matched filters for the compression of impulses/momenta/pulses more frequently are fulfilled on the base of ultrasonic delay lines (ULZ). The sound propagation velocity, as is known, considerably less than the velocity of propagation of radio waves. This makes it possible to obtain sufficiently long delay time with comparatively low sizes/dimensions of ULZ. The conversion of electrical oscillations/vibrations into the mechanical ones (ultrasonic) and vice versa in such filters is based on the use of straight/direct and reverse piezoelectric effect. For example, the properties of piezoelectric effect the crystals of quartz possess. However, they are characterized by narrow passband, in connection with which they cannot be used in the filters of the receivers of radars, since to almost all without the exception/elimination radar signals is distinctive wide frequency spectrum.

The series/row of the new principles of the construction of ultrasonic delay lines was developed in recent years. Some of them are characterized by a comparatively large broad-band character, which makes it possible to apply them in radars. For example, ultrasonic delay lines of strip/tape type with the constant thickness and wire lines have a passband of frequencies from 100 to 1000 kHz strip delay lines with variable thickness - from 500 kHz to 4 MHz, diffraction lines - from 1 to 10 MHz and delay lines with the

propagation of ground waves - from 10 to 50 MHz.

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The waveguide, which works near the critical frequency, can be used as the matched filter. For an increase in its effective length (size decrease) one end/lead of the waveguide is made by that short-circuited. The waveguide is bent for the purpose of the decrease of sizes and convenience in the arrangement/position of filter. Waveguide filters possess large broad-band character, by low losses and are more simple in structural/design sense in comparison with other systems of compression.

Matched filter provides not only the compression of impulses/momenta/pulses. Owing to its use, there is reached also maximum signal-to-noise ratio at the output of receiver. The amplitude-frequency characteristic of matched filter repeats the analogous characteristic of the sounding signal with certain scale factor. Therefore through the filter are passed only those components of noise, whose frequencies correspond to the spectrum of useful signal. The remaining noises (in them it is contained the very significant part of the energy of noise) are suppressed by filter.

In the devices/equipment of compression satisfaction of the

conditions for the complete agreement of filter is undesirable on that reason, that the signal with rectangular distribution of the spectrum after the passage through the matched filter has a spectrum, which is changed in the time according to the law (sin x)/x. A similar law of spectral change leads to the appearance of the minor lobes, whose level can reach 20% of the fundamental maximum, and in certain cases it becomes comparable with it. The presence of minor lobes worsens/impairs the characteristics of radar, especially with its work on several objects. They lead to the appearance of false marks on the scope of RLS, and they can lead into deception of the operator of station. In this main disadvantage in the matched filters.

To improve the shape of the envelope of the compressed impulse/momentum/pulse, or, in other words, to decrease the side-lobe level, is possible by replacing the matched filter by filter with the bell-shaped amplitude-frequency characteristic. The passband of this filter Δf_p is taken somewhat less than the deviation of the frequency Δf of the sounding signal. For example, the contraction of the filter pass band to 40% with respect to the deviation of the carrier frequency decreases the first overshoot almost doubly in comparison with the value of analogous overshoot at the output of matched filter. However, with the contraction of passband to 60% first overshoot it decreases almost 40 times.

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Weakening minor lobes due to the contraction of the filter pass band is accompanied by distention in the time of main impulse. However, its expansion is comparatively small and comprise in the first case approximately 8%, and the second, approximately 36%.

Most frequently the weakening of minor lobes in the systems of the compression of impulses/momenta/pulses is achieved by the use of supplementary processing of signals, which consists in the fact that the impulse/momentum/pulse compressed with the aid of the matched filter is passed through the supplementary filter. So that the minor lobes would not exceed the assigned levels, it is necessary to fit this form of the amplitude-frequency characteristic of supplementary filter, with which the change in the time of the spectrum of signal at its output would differ from the function of form (sin x)/x. A similar treatment makes it possible to obtain the side-lobe level on 40 dB of lower than the level of fundamental maximum. However, the duration of the compressed pulse increases in all by 40-50%, but signal-to-noise ratio decreases by not more than 2 dB.

A correction of the shape of the envelope of the compressed

impulse/momentum/pulse can be realized on the high, the intermediate or the video frequency. For example, the correction of the compressed impulse/momentum/pulse on the video frequency is conducted by selecting the time constant of the load of detector, whose decrease leads to the considerable weakening of minor lobes. Regulating the value of load, it is possible to obtain the most advantageous form of main impulse and the permissible side-lobe level.

For weakening of minor lobes is applied and the so-called predistorted frequency modulation. Predistortion consists in the fact that in the beginning and end/lead of the impulse/momentum/pulse (see Fig. 7c, line 2), i.e., during the time Δt, the carrier frequency changes with the larger rate than in the middle of impulse/momentum/pulse. The parameters of predistortion are Δt and Δf_p. For example, when $\Delta t=1.2/\Delta f$ and $\Delta f_p=0.6\,\Delta f$ lateral lobes decrease by 6 dB in comparison with the lobes/lugs, which are formed with linear modulation, and their level on 40 dB is lower than the amplitude value of fundamental maximum. Theoretically minimum side-lobe level at the output of filter is obtained when the parameters of predistortion are respectively equal to $\Delta t=1/\Delta f$ and $\Delta f_p=0.75\,\Delta f$, where Δf - deviation of signal frequency.

Minor lobes appear not only as a result of processing signal by matched filter. As the reason for their appearance can serve the

distortions, introduced into the frequency modulated signal by the parasitic amplitude modulation, which most frequently is caused by pulsations in the modulators, capacitor discharges, by disagreement/mismatch of load from one cascade/stage to the next and by pulsations of voltage in the transformers.

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Due to the parasitic amplitude modulation at the output of filter together with the main impulse there appear two paired (lateral), which are called echo pulses. They are arranged/located at a distance $\Delta\tau = \pm(f_m/\Delta f)\tau_1$ from the main impulse (where f_m — frequency of the distorting, Δf - deviation of frequency, τ_1 - duration of the frequency modulated pulse). These distortions also are considered during the design of the devices/equipment of compression.

Radars, in which is utilized frequency modulation, have a higher resolution and an accuracy of ranging with the work on the stationary targets. But if object moves, then each spectral component of the frequency modulated impulse/momentum/pulse due to the Doppler effect obtains bias/displacement in the frequency and therefore in transit through the filter additionally it delays to period $\Delta t = 2v_r\tau_1\tau_2/\lambda_0$ (where v_r —the radial velocity of object, λ_0 - average/mean wavelength). The temporary/time time lag of output pulse indicated leads to the error

in ranging and certain deterioration in the resolution.

The principle of the compression of impulses/momenta/pulses examined provides for the frequency modulation only of the sounding signal. However, the frequency of the signal of heterodyne remains constant/invariable in the time. This method most frequently is applied in the search radars.

Is somewhat otherwise solved the problem of an increase in the resolution by the compression of impulses/momenta/pulses in the tracking stations of objects. In them frequency modulation undergo the sounding, and heterodyne signals. Since sounding pulse is modulated in the frequency, then the instantaneous values of frequencies in the impulses/momenta/pulses, reflected from the objects, which are located on different distances, will differ from each other. The difference in their values because of the linear law of modulation will prove to be proportional to the ranges between the objects. The characteristics of heterodyne and sounding signals are completely identical. Therefore, as a result of interaction of the signals accepted by station with the signal of heterodyne are formed several intermediate frequencies, whose presence makes it possible to distinguish the accompanied objects.

A similar principle of compression is very effective; however,

it requires the considerable complication of radar and, in particular, use/application of an analyzer of spectrum of signals, capable of distinguishing the frequencies, which differ between themselves to the very low value.

Range resolution in contemporary radars, which work with the compression of impulses/momenta/pulses, in certain cases reaches several meters. It was possible to obtain such results because of the high level of the development of technology of compression.

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MONOPULSE RLS.

Monopulse radar began to be developed in the postwar period. The intense research and designing of Soviet and foreign specialists preceded the appearance of specific models of RLS with the monopulse method of measuring the coordinates.

The fiftieth and sixtieth years were characterized by the rapid development of aviation equipment, by a sharp increase of the velocities of aircraft and by a considerable increase in altitude and range of their flight. Simultaneously rocket engineering intensely was developed with the aviation. All this advanced a number of new,

more rigid, requirements for the radar, such, as an increase in the range, an increase in the accuracy of the measurement of coordinates and reliability of the accompaniment of objects, shortening time to obtaining of information about the objects, increasing the noise suppression of radars, etc.

Principles of construction existed at that time and methods of measuring the coordinates, based on the treatment of the sequence of impulses/momenta/pulses, did not make it possible to obtain the required charac- -istics of stations. The created position forced scientists, designers and wireless engineers to direct its efforts/forces for the development and practical realization of the fundamentally new method of measuring the coordinates, which subsequently made it possible to sharply improve many characteristics of RLS: the accuracy of measurements, interference shielding, reliability, etc. New method was called monopulse. (Word "mono" in the translation/conversion into the Russian language indicates one. Respectively and method is occasionally referred to as single-impulse). In the single-pulse measurement of coordinates all information (range, azimuth and angle of elevation) about the spatial position of object is obtained from one echo pulse.

Monopulse RLS are capable of observing and of measuring coordinates simultaneously of several objects, in connection with

which they can be used as survey. However, such stations found the widest application in the systems of automatic tracking of high-speed objects.

Earlier has already been noted that in RLS, which use for the accompaniment a method of the conical scanning of ray/beam, the error signal, with the help of which is realized the position control of antenna (coincidence of its optical axis with the direction to the object), is formed/shaped from the envelope the amplitude-modulated impulses/momenta/pulses, reflected from the object.

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In order to obtain the value of signal, sufficient for the effective control of antenna, object must be irradiated by several impulses/momenta/pulses, or, as they say, in the sequence of impulses/momenta/pulses. During irradiation by sequence is required a comparatively large time interval, during which the angular position of the observed object can change relative to radar.

Taking into account layout and the physical properties of object, it is not difficult to be convinced of the fact that its effective reflecting surface with different angles of approach does not remain constant. Its changes occur according to the random law

and are called fluctuations. The period of fluctuations can vary from the tenths of second to several seconds. It depends also on wavelength, on which works radar.

Due to the fluctuations of the effective reflecting surface into the sequence of the impulses/momenta/pulses, modulated in the amplitude as a result of conical scanning, supplementary components of modulation are introduced, their level under the different conditions for radar surveillance and in the parameters of the motion of object reaching several ten decibels. Therefore in the stations with the conical scanning the effect of the fluctuations of the effective reflecting surface of object can prove to be very essential and considerably lower accuracy of the RLS.

The deficiency/lack indicated almost completely is removed, if the measurement of coordinates produced according to the information of one impulse/momentum/pulse, i.e., with monopulse method. The spurious modulation of the echo signal, caused by changes in the effective reflecting surface of object, virtually completely is absent in this case. If we consider the durations of pulses (unit of microseconds), used in radars, and the rate of real objects, then it appears that for the exposure time by one impulse/momentum/pulse the angular position of object relative to RLS remains constant/invariable, and consequently, does not change its reflecting

surface.

The measurement of coordinates by monopulse method in one plane requires the use/application of two antennas (Fig. 9), the radiation patterns of which partially overlap each other (Fig. 10a), as in the case of the method of the equisignal sector (see Fig. 4c). The same effect can be obtained, utilizing reflector or lens type one antenna with two irradiators, whose alignment makes it possible to form/shape two-lobe diagram with the equisignal direction.

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Four antennas (two in each plane) are required for measuring the angular coordinates (azimuth and angle of elevation) in two planes or, it is analogous with the preceding/previous case, it is possible to use one reflector or one lens with four irradiators.

In monopulse RLS the measurement of coordinates is made on the base of the comparison of amplitudes or phases of signals, accepted on different lobes/lugs of radiation pattern.

The principle of the operation of station is explained with the aid of the block diagram, shown in Fig. 9.

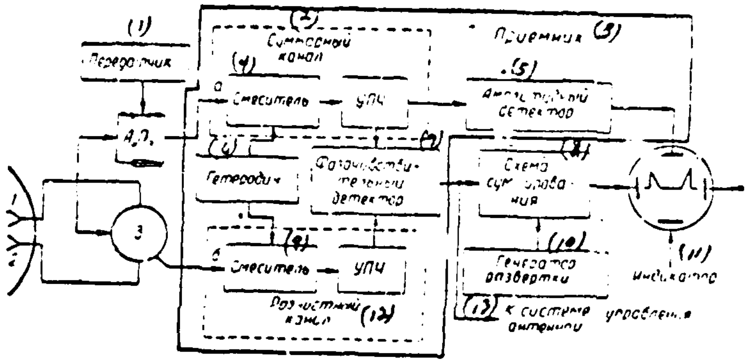

Fig. 9. Block diagram of monopulse RLS with the comparison of amplitudes.

Key: (1). Transmitter. (2). Total channel. (3). Receiver. (4). Mixer. (5). Amplitude detector. (6). Heterodyne. (7). Phase-sensitive detector. (8). Diagram of summation. (9). Mixer. (10). Sweep oscillator. (11). Indicator. (12). Differential channel. (13). To system of control of the antenna.

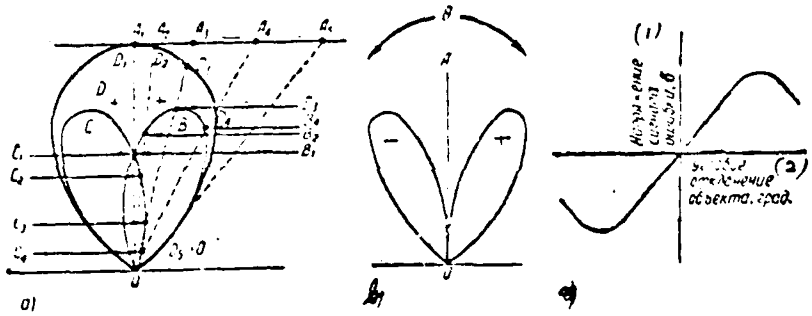

Fig. 10. Radiation patterns (total - a, differential - b) and direction-finding characteristic - c.

Key: (1). Voltage of the error signal, in. (2). Angular deflection of object, deg.

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In the set included are: the antenna with two irradiators 1 and 2, transmitter, phasing ring 3, antenna switch АП, receiver and indicator. In it is provided for the measurement of one angular coordinate via the comparison of the amplitudes of the signals accepted.

Antenna system forms/shapes two-lobe radiation pattern. The reception of the signals echo from the object is conducted simultaneously along both lobes/lugs.

The connection/communication of antenna with transmitter and receiver of station is realized with the aid of waveguide type phasing ring. In the mode of radiation/emission the ring has one input (from the transmitter) and two outputs (to two irradiators), while in the reception mode - two inputs (on both lobes/lugs) and two outputs (to two channels of receiver). The alignment of receiving inputs and outputs of ring (in the portions of working wavelength) is carried out in such a way that from one output is taken the sum of signals (into the total channel), and from another - their difference (into the differential channel). A similar method of treatment in the high frequency of echo from the object and accepted by station signals forms in the reception mode total and differential radiation patterns respectively.

Let us examine how is formed/shaped, for example, total radiation pattern (see Fig. 10a). Let us agree that the signal amplitude, accepted on any lobe/lug of the diagram of "radiation/emission", is proportional to its ordinate. Taking into account the condition accepted, it is possible to say that if the observed object is located on the equisignal direction (line OA_1), then the signal echo from it at the output of total channel will be proportional to the sum of ordinates $OB_1+OC_1=D$ or to the doubled

value of ordinate $OB_1=OC_1$. During the bias/displacement of object to the small angle from the equisignal line, for example into point A_2, the sum of ordinates $OB_2+OC_2=D_2$, which characterize its position, barely will change in comparison with D_1. and consequently, will not change the amplitude of total signal at the output of the phasing ring. If the observed object proves to be at point A_3, i.e., it will be displaced to a comparatively large angle relative to equisignal line, then the sum of ordinates $OB_3+OC_3=D_3$ will be less than the ordinate D_1, which is obtained, when object is located on the equisignal direction. With respect to this the amplitude of total signal decreases at the output of the phasing ring. The position of object, which is found on line OA_4, is characterized by the total ordinate D_4, which is determined virtually only by ordinate OB_4 of lobe/lug B of radiation pattern, since the value of ordinate OC_4 of lobe/lug C can be disregarded/neglected in view of its smallness. In the limit during the location of object on line OA_5 (at any point of it) the resulting ordinate will be equal to zero ($D_5=0$).

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Now, if we connect the points (D_1, D_2, D_3, D_4, D_5), constructed as a result of the summation of ordinates (in different angular positions of object relative to equisignal direction), we will obtain total half-radiation pattern (right in Fig. 10a) in the mode of

reception (it is designated by the thickened curve). With the divergence of object to the left side from the equisignal line will be obtained the curve, the completely symmetrical of the right side of total half-pattern.

Differential (Fig. 10b) radiation pattern, when signal is removed/taken from output b of the phasing ring, is constructed analogously.

For the total diagram line OA_1 is the direction of the maximum of reception, while for the differential - by direction of zero reception.

From outputs of the phasing ring high-frequency signals enter the mixers of the total and differential channels, where they are converted into the lower, intermediate frequency. Conversion in both channels is realized with the aid of one and the same heterodyne. The total and differential signals of intermediate frequency are amplified by separate UPCh and after amplification enter the phase-sensitive detector. Total signal, furthermore, it is supplied to the amplitude detector and subsequently is utilized for ranging to the observed object.

Total and differential signals at the input of phase-sensitive

detector are located in the phase, if object is arranged/located on one side from the line of the equisignal direction (for example, to the right of it, as shown in Fig. 10a and b) and in the antiphase - if it is displaced to the opposite side (to the left).

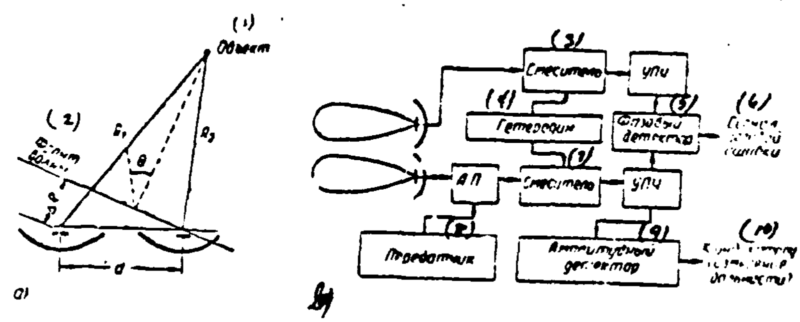

Fig. 11. Monopulse method of determining the coordinates via the comparison of the phases of signals.

Key: (1). Object. (2). Wave front. (3). Mixer. (4). Heterodyne. (5). Phase discriminator. (6). Signal of angular error. (7). Mixer. (8). Transmitter. (9). Amplitude detector. (10). To indicator (ranging).

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Similar phase relationship makes it possible to utilize a total signal as the sign of angular error supporting/reference during the determination. The value of angular deflection is proportional to the amplitude of differential signal.

Thus, one impulse/momentum/pulse, accepted by radar according to two radiation patterns (total and differential), makes it possible to

determine range to the object, and also sign and value of angular error. Fig. 10c gives the direction-finding characteristic of phase-sensitive detector. It shows the dependence of the voltage of the error signal on its output from the displacement angle of antenna.

After the appropriate amplification the output voltage of detector is supplied to the motor, which turns antenna in such a way that its axis would attempt to coincide the direction to the object. With a continuous change in the position, the error signal will exist always, and the antenna of RLS, following its changes, will automatically accompany object.

Observation of the object and measurement of its coordinates are conducted with the aid of the indicator. For this into the display unit the output signals of the amplitude and phase-sensitive detectors (see Fig. 9) are supplied. The first of them enters the vertical deflectors of cathode-ray tube. It causes the divergence of electron beam upward, forming on the sweep trace marker, with the aid of which it is estimated distance to the observed object. The second signal - from the phase-sensitive detector - is supplied to the horizontal deflectors of tube. Its effect leads to the bias/displacement of sweep trace, as a result of which the marker is deflected to the left or to the right depending on the sign of

angular error.

If the reader can arise a question, why the method of measuring the coordinates examined is called amplitude, if the discussion does deal with the comparison of phases? The fact is that phase itself does not bear information about the value of angular deflection. This information is contained in the amplitude of differential signal, and the comparison of phases is utilized only for determining the direction of the divergence of object to that or other side from the equisignal line, i.e., for determining the sign of angular error.

In the monopulse radar the angular coordinates can be measured also with phase-difference method, utilizing information about the position of object, that contains in a phase difference of the signals, accepted by antennas. The measurement of one angular coordinate by the method of comparison of amplitudes, as it is already known to the reader, possibly only in such a case, when radiation patterns partially overlap, forming equisignal direction.

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And in order to form this diagram, the irradiators of antenna system must be displaced in the opposite directions from the center of reflector (its optical axis).

For measuring one coordinate by the method of comparison of phases are also required two antennas. However, the axes of the radiation patterns formed/shaped by them in contrast to the method of comparison of amplitudes must have bussing arrangement. It is completely obvious that such diagrams cannot be created with the aid of one antenna. For this it is necessary to have two independent (separate) antennas (Fig. 11a), moreover they must be spread up to certain distance of d, determined by the length of transmitting wave of radar. With this execution of antenna system each of the antennas irradiates one and the same space of space in the remote zone. Therefore the signals, reflected from the object and accepted by station according to both diagrams, have virtually identical amplitudes, and their phases differ by the value of $\Delta\varphi$, proportional to a path difference of rays/beams ΔR (see Fig. 11a). A phase difference is determined by expression $\Delta\varphi=2\pi/\lambda\cdot d\cdot\sin\Theta$, where λ - wavelength, d - distance between the antennas (base), Θ - angle, formed by the line of the sighting of object and by the axis, perpendicular to the line, which designates the wave front. At small angles, when $\sin\Theta\approx\Theta$, and phase difference $\Delta\varphi$ depending on angle Θ changes according to the linear law and can be used as the signal of angular error.

The method of measuring the phase relationships/ratios of signals, accepted by the spaced antennas, extensively is used in the radio astronomy and is called radio-interferometric. True, in the radio astronomy this method is passive, since the radio emissions, emitted directly by the objects (neonon/without- bodies), which are subject to observation, are utilized as the signals. Radar with the phase-difference method of determining the coordinates by analogy also can be named/called interferometer, but already active. However, more frequent such stations are called RLS with the simultaneous comparison of phases or monopulse RLS with the comparison of phases.

The most essential differences in radar, in which for measuring the coordinates is applied phase-difference method with RLS with the comparison of amplitudes, are reduced in essence to the following.

First, as already mentioned, phase monopulse RLS have two separate antennas (see Fig. 11), which form the independent radiation patterns, moreover one of the antennas is connected to the receiver and the transmitter (certainly, through the antenna switch), and another is connected only with the receiver. Naturally it is not required in the channel which operates only on the reception, the antenna switch for the protection of input circuits of the receiver.

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Virtually it is always included in the diagram. Its use/application is caused by the need for obtaining completely identical phase responses of both channels of the receiver of station.

In the second place, in radars with the comparison of phases the need for the high-frequency phasing ring is eliminated, since with this method of measuring the coordinates summation and subtraction of signals is not required to produce.

Thirdly, instead of the phase-sensitive detector (RLS with the amplitude method) the phase discriminator, which reacts to a phase difference of signals, is applied. The output voltage/stress of phase discriminator also characterizes value and sign of angular error and is utilized for the rotation of antenna during the accompaniment of object.

The composition and the principle of operation of both types of stations are analogous in other respects (see Fig. 10b).

Phased-array radar.

The phased antenna array presents the device/equipment

(occasionally referred to as matrix/die), which consists of a large number of electrically free between themselves elementary antennas, which radiate or which accept electromagnetic energy. Subsequently, we will call elementary antennas the elements/cells of grating. Their functions can fulfill half-wave dipoles, waveguide horns, etc.

The development of radars with the antennas of the type the phased grating was begun comparatively recently. It became possible because of the achievements of recent years, obtained in different branches of radio-electronic technology. The special features/peculiarities of such stations include: the polyfunctionality, the absence of limitations to the radiated power, the electronic scanning of ray/beam, the high rate of the survey/coverage of space, programmed control of radiation pattern and high reliability.

Term "multifunctional" means that one and the same station can fulfill the series/row of functions, for example, to detect and to accompany ground-based and air objects, to chart and to follow area relief, to provide low-altitude flights, etc. During the use usual type of RLS the functions indicated are fulfilled by several specially intended for these purposes radar stations.

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In phased-array radar high power levels are formed in the space as a result of the summation of the electromagnetic energy, emitted by many elementary antennas. However, comparatively low-power generators are utilized in the transmitters. Therefore the limitations, placed on the amount of radiated power by the breakdowns of radio engineering elements/cells, so/such characteristic for very powerful RLS with the usual antennas, almost completely are absent.

The electronic methods of scanning, used in the stations with the phased gratings, make it possible to sharply shorten the time, required to the survey/coverage of space (i.e. to increase the rate of survey/coverage). Furthermore, is created the real possibility of the programmed control of radiation pattern, which is realized with the aid of electronic computers. In RLS with the computers phased by gratings they are integral part.

Because of the noted special features/peculiarities of the RLS of the considered/examined type they are considered as the extremely promising. They will have extensive application in the solution of the most diverse problems: providing safety of floating vessels in the seas and the oceans, the air traffic control (especially in the large/coarse airports) and many others.

The phased antenna arrays can be classified to the passive ones and the active ones. By passive is understood the grating, which consists of many radiating elements excited by one or several sources of shf energy. During the excitation of elements/cells by one source use/application of a grating gives gain in essence in the rate of the survey/coverage of space (due to the electronic beam control). The maximum radiated power in this case is determined by the source power of energy, which excites the elements/cells of grating. It, as has already been indicated, is limited to the possibility of the breakdowns of radio engineering elements/cells in the transmitter and the receiver. In order to increase radiated power, without fearing the breakdowns, they divide grating in the section, each of which is excited by their independent source. In this case the amount of the power of the separately undertaken energy source decreases inversely proportional to their quantity, which virtually completely excludes the possibility of breakdowns.

Impulse cascade can consist of the elements/cells, made in the form of the moduli/modules, capable of fulfilling the functions of transmitter and receiver. In this case each element/cell of grating will present the elementary receiving-transmitting circuit. Schematic diagram and work of one of such moduli/modules are examined at the

end of the section.

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In the radar the widest acceptance obtained two types of gratings - linear and flat/plane. Linear grating consists of the n elements/cells, arranged/located into the line, flat/plane - presents the two-dimensional layout of elements/cells. As a rule, the elements/cells of grating have a uniform distribution on antenna aperture. However, this arrangement/position is not always optimum. Are possible the cases, when the nonuniform distribution of elements/cells makes it possible to obtain the same parameters of antenna system at their considerably smaller quantity. The selection of an optimum quantity of elements/cells and law of their distribution on the aperture of grating - sufficiently complex problem, which is solved privately in each specific case.

In contrast to usual type antennas (lens, mirror, etc., which have radiation pattern it is formed/shaped, correspondingly, with reflector or by lens) in the grating phased by antenna the necessary phase relationships/ratios, which require for shaping of radiation pattern, are provided before the radiation/emission of energy - in the feeder lines, which feed separate elements/cells. For this purpose in the feed circuit (in the high frequency) of each element

is included the phase inverter, with the aid of which the relative phases of signals are selected in such a way that the radiation pattern of the assigned form would be formed as a result of the combined action of the elements/cells of grating.

The principles of the formation of the radiation pattern and electronic scanning of ray/beam for simplicity let us examine based on example of the antenna array, which consists of two elements/cells (Fig. 12), high-frequency energy to which is supplied from the common source.

It is known from a course of electrical engineering that the electrical and magnetic fields can be represented in the form of vectors. Electrical field component, created by left (see Fig. 12a) emitter, is characterized by vector $\vec{E}_1$, and electrical field component, created by right emitter - vector $\vec{E}_2$. The total field, characterized by vector $\vec{E}_3$, is formed as a result of vectorial addition (Fig. 12b). The modulus/module (numerical value) of vector $\vec{E}_3$ determines the amplit e of the resulting signal, and the angle, to which is turned the vector - direction of propagation of electromagnetic energy.

The angular position of vector $\vec{E}_3$, as can be seen from Fig. 12b, c, d, mainly depends on phase relationship between $\vec{E}_1$ and $\vec{E}_2$. Let us

designate their φ_1 and φ_2, respectively. With $\varphi_1=\varphi_2$ vector $\vec{E}_3$ will have the same direction, as $\vec{E}_1$ and $\vec{E}_2$.

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Now let us give positive increment $\Delta\varphi$ to phase φ_2; in this case the resulting vector E_3 (Fig. 12c) will be displaced to the right with respect to $\vec{E}_1$ to the angle, proportional to $\Delta\varphi$. If we give decrement ($-\Delta\varphi$) (Fig. 12d) to phase φ_2, then vector $\vec{E}_3$ will be displaced to the left to the angle, also proportional to $\Delta\varphi$.

It was previously indicated that the position of vector $\vec{E}_3$ characterizes the direction of propagation characterizes the direction of propagation of electromagnetic energy. Consequently, a continuous change of the relative phase of signals in the elements/cells of grating will cause scanning ray/beam in the space. The given considerations remain valid for any quantity of elements/cells. The initial phasing of signals is fulfilled in such a way that the maximum of radiation/emission (ray/beam of antenna) would be oriented perpendicular to the plane of grating.

The sector of the survey/coverage of radar with the antenna phased array depends on the distance between the single elements of antenna system and form of the radiation pattern of the separately

undertaken element/cell. Contemporary radars are capable of examining/scanning space in sector of ±5°. can be obtained large viewing angles, but the expansion of ray/beam occurs in this case and increases side-lobe level. Beam width changes approximately inversely proportional to cos Θ, where Θ - angle of deflection of ray/beam from the normal to the plane of antenna array. The dependence indicated is valid only for the small angles of deflection; at the large angles it loses force. When RLS must have the wide sector of survey/coverage, most frequently are applied dipole elementary antennas, since they possess the properties of the almost nondirectional radiation/emission and reception. If the required sector of coverage is not very great, then as the elementary antennas it is possible to utilize the elements/cells, which possess the large directivity: dielectric rods, and also helical, spiral and logarithmic-periodic antennas.

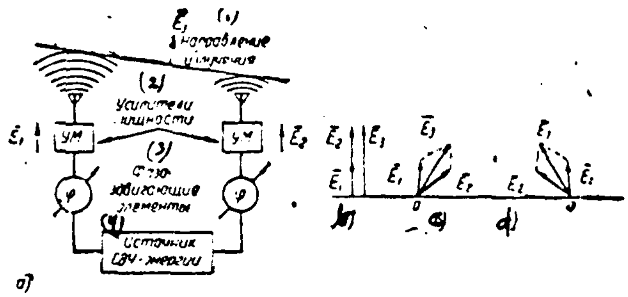

Fig. 12. To the explanation of the principles of the work of the antenna of the type the phased grating and the electronic scanning of ray/beam.

Key: (1). Direction of radiation/emission. (2). Power amplifiers. (3). Phase-shifting elements/cells. (4). Source of shf energy.

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The width of the radiation pattern of the phased antenna array as any other antenna, is determined by the area of its aperture, i.e., by geometric dimensions. Taking into account that the distances between the elements/cells in the real gratings are usually taken by equal ones to (0.5-0.6)λ, it is possible to determine the quantity of elements/cells, which will be placed over the assigned area of aperture. Thus, a quantity of elementary antennas serves as the equivalent of the area of aperture and can be used for the

approximate evaluation/estimate of the width of radiation pattern. For example, the width of the radiation pattern of linear grating (at the level of half power) is determined by expression θ=010.8/n, where n - quantity of elements/cells. It is possible to solve inverse problem, i.e., to determine the necessary quantity of elements/cells in the grating. In order to create the ray/beam with a width of 1° in one plane, as it is known from the course of the design of antenna design, the geometric dimension of antenna must be equal to 60 lengths of transmitting wave. During this condition and arrangement/position of elements/cells in the grating at a distance, for example, 0.6λ from each other for the formation of the ray/beam indicated it will be required n=60λ; 0.6=100 elements, and in order to create a ray/beam of "pencil" type of 1°×1°, it is necessary to have on 100 elements/cells in each series/row of both grating measurements, i.e., 10000 pieces.

In the antenna to the phased grating the level of the first minor lobe at sufficiently high values of n is lower than the level of principal ray by 13.5 dB, and the level of latter/last minor lobe is inversely proportional to the square of a quantity of elements/cells, i.e., it is equal to $1/n^2$. Gratings, in which the elements/cells are arranged/located on the distances, about $\lambda/2$, have comparatively small minor lobes. With an increase in the distance they sharply grow/rise and can reach the values, equal to the level

of the fundamental ray/beam of radiation pattern. Such minor lobes are called secondary principal maximums. They appear, for example, with the distances between the elements/cells, equal to 2λ, and they are inclined at an angle of $\theta=\pm30°$ and $\theta=\pm90°$ with respect to the axis of fundamental ray/beam. The sence of secondary principal maximums leads to the ambiguity in the determination of angular coordinates and the appearance of false marks, because it is not possible to distinguish the objects, seen on secondary major lobes, of the objects, seen on the fundamental ray/beam.

The virtually required phase relationships/ratios in the elementary antennas can be obtained with the aid of the device/equipment with the consecutive or parallel diagram of feed.

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In series circuit (Fig. 13a) the energy to the elements is supplied from any side of grating or to its center. In the latter case the energy is propagated from the center of grating to its both ends/leads. The radiating elements/cells are divided by the phase inverters, which create identical phase shift. Let us assume that the initial phase of the first element/cell of grating φ_0 and each phase shifter creates phase shift $\Delta\varphi$. Then the phase of the nth element in series circuit of feed is determined by expression $\varphi_n=\varphi_0+\Delta\varphi(n-1)$, where n - quantity of elements/cells in the

grating. Main disadvantage in this diagram - large losses, introduced by the phase inverters, for compensation for which is required the use/application of special amplifiers. The positive property of series circuit of feed in the fact that the position control of ray/beam in the linear grating is realized only one control signal, and in the flat/plane - by two signals.

In the parallel diagram of the feed (Fig. 13b) of loss in each circuit they are introduced only by one phase inverter. Therefore the requirement for the supplementary amplifiers drops off, what is essential advantage. A deficiency/lack in the parallel diagram consists in the fact that for the attitude control of ray/beam in the linear grating is required (n-1) the control signals (signal of the first element/cell it has zero phase), where n - quantity of elements, and in the foil lattice - ($n+\kappa-2$) the control signals, where n and κ - quantity of elements/cells in two mutually perpendicular measurements of antenna array. The device/equipment of programming phase relationships/ratios in the elements/cells considerably becomes complicated as a result.

Main disadvantage in phased-array radar - their structural/design and operating complexity. A large number of active and passive elements/cells in different combinations is created several thousand and even tens of thousands of signal channels. Their

tuning/adjusting, control of characteristics and trouble-shooting, naturally, cause considerable difficulties and cannot be carried out without the special checkout equipment.

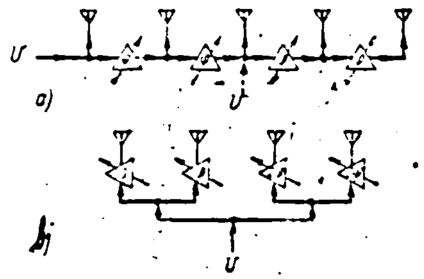

Fig. 13. Antenna arrays with the consecutive (a) and parallel (b) feed.

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Antenna switch provides the decoupling of circuits along transmission channels and reception of more than 20 dB. Insertion losses are approximately 1 dB. Half-wave dipole is utilized as the radiating element/cell. It is supplied from the slot resonator, which simultaneously serves as the adapter between the unsymmetric strip line and the symmetrical antenna feeder.

The signal accepted by antenna through the antenna switch enters the broadband balance mixer. The heterodyne signal with a frequency of f_1 obtained from the signal with a frequency of f_2 after its fourfold multiplication, is supplied here. The multiplier of heterodyne signal is analogous to the multiplier, utilized in the

transmitting channel. The signal of intermediate frequency is isolated as a result of interaction of the taken and heterodyne signals by the output of mixer. Its amplification is realized in the three-stage amplifier, which has factor of amplification 20 dB. General/common/total noise factor of mixer and intermediate-frequency amplifier of approximately 10.5 dB.

Thus, one modulus/module fulfills the series/row of the functions: preliminary amplification and multiplication of the sounding and heterodyne signals. power gain of the emitted signal, mode switch of work from the transfer to the reception and vice versa, radiation/emission and reception the transformation of high-frequency signals into the signals of intermediate frequency and their amplification.

The output signals of the intermediate frequency of all moduli/modules through the commutating system are supplied for further processing, as a result of which is formed/shaped the radiation pattern of the assigned form with the minimum side-lobe level. The possibility of summation and subtraction of the signals of intermediate frequency, which enter from four identical sections of antenna array, is provided in the commutating system. The presence of total and differential channels makes it possible to determine the coordinates of the discovered object by monopulse method.

In radar in question has the capability of work with the intra-pulse linear frequency modulation, and also in conditions of the alternation of signals with linear FM and without it. This operating mode is provided for so that radar could ensure required range resolution at the low (without FM) and large (with the use/application of FM) distances.

Let us note in conclusion that, although phased-array radar are more complicated in comparison with usual type of RLS, they are undoubtedly more promising and are widely applied.

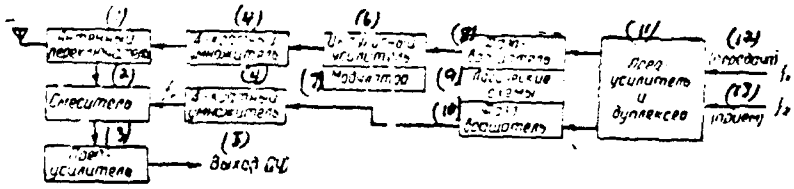

Fig. 14. Block diagram of high-frequency modulus/module.

Key: (1). Antenna switch. (2). Mixer. (3). Preamplifier. (4). 4-fold multiplier. (5). Output of PCh. (6). Pulse amplifier. (7). Modulator. (8). Phase switcher. (9). Logic circuits. (10). Phase inverter. (11). Preamplifier and duplexer. (12). Transmission. (13). Reception.

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Electronic shf- instruments, used in the radar.

In the first decades after the invention of radio there was an only method of exciting the electromagnetic high-frequency oscillations. It was based on the discharge of the oscillatory circuit through discharger. Approximately/exemplarily the era of electron tubes was begun from 1920. Initially electron tubes were used for the voltage amplification of audio frequency, obtained after detector. As electronic technology developed, the functions of electron tubes continuously were expanded. They successfully began to be utilized for the voltage amplification of high frequency in the range of long waves.

Later in connection with the transition/junction from the long waves to the averages and the new, more advanced tubes with the low interelectrode capacitances, which could provide a good amplification at the high frequencies, were required by short ones. This problem was solved as a result of developing screen-grid tetrode - tube with two riding-crops (1924). By several years more lately appeared tubes

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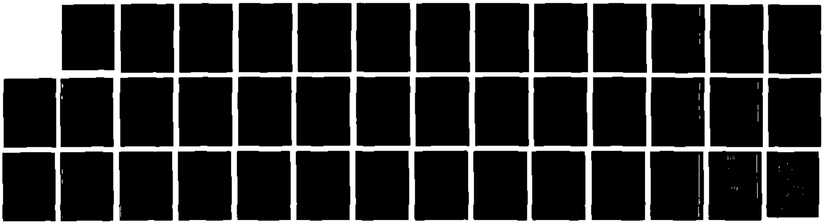

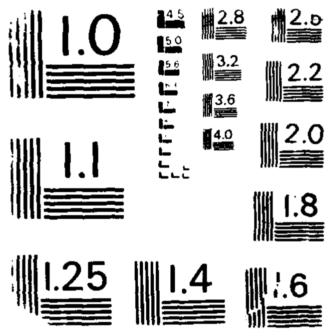
1.0
4.5
5.0
5.6
2.8
2.5
3.2
2.2
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4.0
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1.25
1.4
1.6

triple grid - pentodes (1930-1931).

The development of the special methods of radio reception caused the appearance of new types of multigrid tubes (1934-1935), intended for the frequency conversion. Were created also the diverse multiple-unit tubes, whose use/application made it possible to considerably decrease the total number of tubes in the radio receiving equipment. The question about the improvement of those already being and the development of new electronic devices came up with the transition/junction of radio engineering to mastery/adoption and use of meter, decimeter and centimeter bands. Thus, in 1935 appeared tubes of the type "acorn", cermet triodes were developed in 1938, and in 1944 - lighthouse tubes.

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Tubes were widely applied not only for the amplification and transformations of electrical signals; they were adopted as the generators of high-frequency energy. Because of development and use/application of electronic amplifier and generator instruments radio engineering in its development achieved enormous successes.

With the advent of continuous wave oscillators and amplifier electron tubes spark transmitters proved to be the very

F#:

powerful/thick sources of interferences. Therefore their use was forbidden by the special international solution, accepted on 1 January 1940.

For the generation of electromagnetic energy and amplification of electrical oscillations/vibrations in the range of frequencies to several thousand megahertz of tube is found wide application and at present. However, the effectiveness of their work and power output sharply decrease with an increase in the frequency. Therefore were undertaken the searches for the new methods of generation and amplifying the oscillations/vibrations of the superhigh frequencies, which led to the creation of fundamentally new instruments, such, as magnetrons, klystrons, the tube of running and backward wave, etc.

Magnetrons - diodes, which differ from usual electric vacuum diodes in terms of the fact that in them the electrons, which fly from the cathode to the anode, undergo the effect not only of electrical, but also of magnetic field. The first constructions/designs of the magnetrons, which obtained subsequently extremely wide acceptance in the radar technology, were proposed and in practice realized by Soviet engineers by N. F. Alekseyev and D. Ye. Malyarov in 1936-1937.

Magnetrons are capable of working (depending on the material,

from which it is prepared is cathode) in the pulse or continuous duty they are utilized as shf oscillators. The retuning of operating frequency (to ±7% of the average/mean value) is realized by the mechanical methods, based on a change in inductance or capacity/capacitance of resonators. Output pulse of power or capacity/capacitance of resonators. The output pulse power of magnetrons reaches 5 MW at the average/mean value of 10 kW, and it composes efficiency (50-60)%.

Klystrons - vacuum-tube instruments, the operating principle of which is based on the transformation of direct current into the variable by changing the velocities of electrons. The first klystrons with the velocity modulation of electronic flux appeared in 1938-1940. During the subsequent years and up to now different types of klystrons due to the series/row of their advantages found wide acceptance in the equipment, intended for the work in the range of shf. They are applied as the generators of electromagnetic energy and amplifiers of electrical signals.

The retuning of frequency in the klystrons is conducted by the electronic method (change in the voltage/stress on its reflector).

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In low-power klystrons the range of retuning reaches 8%, while in powerful/thick amplifier klystrons it does not exceed 5%. Output pulse power in the best samples/specimens of amplifier klystrons composes 30 MW at the average/mean value of 400 kW, factors of amplification - 10^{4}-10^{5}, efficiencies - 35-45%.

Low-power klystrons are applied as the local oscillators in the receivers, and powerful/thick amplifier klystrons - in the output stages of the transmitters of radars.

The tubes of running and backward wave are utilized for amplification and generation of electromagnetic vibrations. Travelling-wave tubes (LBV) are called electronic devices, whose energy of electrons is transmitted to the field of the running electromagnetic wave, which is propagated in the direction of the motion of electronic flux. Instruments, whose energy of electrons is transmitted to the field of the traveling electromagnetic wave, which is propagated in the direction, opposite to the motion of electronic flux, are called backward-wave tubes (LOV).

In contrast to the klystrons, in which are applied narrow-band resonators, into LBV and LOV are utilized the systems, similar to lines with the distributed constants, which do not have sharply pronounced resonance properties. Therefore the tubes of runninq and

backward wave possess the considerably broader band of the amplified frequencies in comparison with the klystrons.

Travelling-wave tubes because of the broad-band character and the low noise level, while carcinotrons [from here on - backward-wave tube] - to large electronic-tuning range found extremely wide application in the electronic equipment, intended for the work in the decimeter, centimeter and millimeter wave bands.

On the level of power output the travelling-wave tubes are subdivided into three categories: low-power (with the low noise level), of average/mean and large power.

Low-power LBV are applied for amplifying the signals in input circuits of the receivers, which work in the microwave range. The factor of the noise, which determines the sensitivity of receiver, and amplification factor, serve as the fundamental parameters, which characterize their quality. Different types of tubes have a noise factor from 6 to [illegible] dB, and factor of amplification 20-30 dB (100-1000 times).

LBV of average/mean power are applied for amplifying the signals of intermediate frequency and for the preliminary amplification of electromagnetic vibrations in the powerful/thick generators of

microwave range.

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Factor of amplification and power output serve as their fundamental parameters; noise level virtually does not have a value. Low-power LBV have a factor of amplification 20-35 dB, and the level of power output - from tens of milliwatts to 1 W. Factor of amplification of LBV of average/mean power is 30-40 dB, and power output is within the limits from one to several ten watts.

Powerful/thick LBV, as a rule, are applied in the output stages of transmitters which work in the continuous and pulsed operations. In contrast to low-power LBV they are characterized by higher efficiency and comparatively narrow band of operating frequencies.

Carcinotrons, possessing the very broad band of electronic retuning, are utilized as the low-power electronic generators. Their efficiency is small and compose a total of several percentages, and power output is within the limits from several ten milliwatts to the units of watts.

On the base of the usual tubes of running and backward wave, in which electronic flux interacts with the longitudinal magnetic field,

are develcped the new types of instruments. In them electronic flux interacts with the transverse magnetic field. Travelling-wave tubes with the transverse magnetic field are called LBV of type M (LBVM), or magnetron amplifiers. They are characterized by the large power output, which reaches several megawatts, by high efficiency (40-50%) and by the broad band of the amplified frequencies - 15%. Factor of amplification of LBVM is approximately 15 dB. Their main disadvantage - high noise level.

Carcinotrons with the transverse magnetic field by analogy with LBV call LOV of type M (LOVM). Their fundamental advantage - very broad band of the retuning of frequencies and high efficiency (about 50%). Power output of LOVM composes several hundred watts.

In recent years successfully are utilized hybrid instruments - the so-called Twystrons, which combine in themselves the best properties of klystrons and LBV. The passband of approximately 15% at the pulse power to 5 MW is achieved/reached in the pulse powerful/thick Twystrons, while in the best samples/specimens of LBV the passband composes 10%, and in klystrons - 8%.

For the achievements of recent years in the region of developing electronic engineering should be related the new instruments, which obtained the designation of mitrons. It is proposed to use them in

the low-noise receivers as the heterodyres, in the systems active radar countermeasures as those frequency modulated the generator of interferences, in measuring equipment, etc.

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Mitrons depending on power and working frequency band are subdivided into three types: the low-power broadband mitrons, which have the power output of 1 W and less, and the ratio of maximum frequency to the minimum - 3; the mitrons of average/mean power (power output from 3 to 150 W; the ratio of maximum frequency to minimum 2); the mitrons of the large power (power output it reaches 500 W; the ratio of maximum frequency to the minimum does not exceed 1.5).

The characteristic feature of mitrons - constancy efficiency. virtually in entire range of retuning in the frequency. The efficiency of these instruments depends on the power output: the higher it is, the higher the efficiencies. For example, at the power output from 1 to 3 W efficiency of mitrons it composes 10-35%, at the power from 5 to 10 W its value is raised to 25-45%, and at the power from 50 to 500 W efficiency it reaches 50-70%.

Mitrons are characterized also by the large ratio of power to

the weight, which is especially important for the equipment, installed on the aircraft.

The parameters of electronic devices constantly are improved: at present is considerably increased by efficiency, power output and reliability, noise level is lowered, is increased stability to the effect of environmental conditions, are developed new, more effective method than the suppression of spurious radiations, which ensure virtually complete safety of the service personnel with the work with the powerful/thick vacuum-tube instruments.

Together with the vacuum-tube instrument ever wider application is begun to obtain solid-state amplifiers and generators. Thus, for instance, Hann's generators, which have very low noise level in comparison with the klystrons, it is proposed to utilize as heterodynes and pump oscillators of parametric amplifiers.

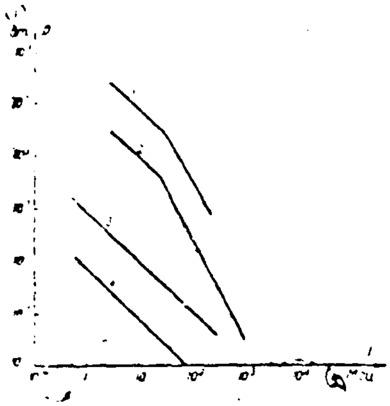

Fig. 15. The dependence of power output on the frequency for shf instruments: 1 - electric vacuum pulse; 2 - continuous electric vacuum; 3 - solid-state pulse; 4 - continuous solid-state.

Key: (1). W. (2). MHz.

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On the level of power output solid-state amplifiers and generators are thus far inferior to vacuum-tube instruments.

Fig. 15 shows the graphs/curves, which characterize the power output of the contemporary electronic solid-state instruments of microwave range depending on frequency. In contemporary vacuum-tube instruments these constants are 10^3-10^4 times more than in solid-state ones. Therefore at present and the next years still will

be extensively used vacuum-tube instruments and especially when large power output is required of the amplifier or the generator. The hypotheses simultaneously are presented that as a result of the rapid development of solid-state amplifiers and generators they already in the near future will begin to compete with the vacuum-tube instruments of the average/mean power at frequencies of below 5 GHz, i.e., with the carcinotrons and the klystrons.

Laser location.

Laser location[1] - one of the new branches of contemporary quantum electronics.

FOOTNOTE [1]. Terms "laser", "optical" and "light", used in this section, have the equivalent sense. ENDFOOTNOTE.

Great achievements in the field of its development, over a comparatively short period of time - result of the numerous theoretical and experimental studies, carried out by Soviet and foreign scientists.

At the base of laser location lies/rests the use of optical or the so-called light range of electromagnetic vibrations. Light/world as observation facility is applied from the old times. For example,

before the appearance of radar light projectors were considered as the fundamental instrument for detection and observing different objects at night; movement on the earth's surface under the conditions of poor visibility and the safety of floating ships under the bad weather conditions was provided with their aid. However, in all these cases the energy, emitted by the light sources, was utilized only for illuminating the objects, and observation of them was realized visually.

The methods of using the luminous energy in the observation facilities changed with the advent of quantum generators and optical amplifiers. Laser generators made it possible to form the light impulses/momenta/pulses of such duration with the energy level, completely sufficient so as to record the signal echo from the object in the point of reception.

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With the use/application of optical lasers appeared the possibility of the isolation/liberation of the echo signal from the entire totality of the electromagnetic vibrations, which affect the input flatten devices/equipment, and its amplification to the level, necessary for the reproduction on the scope. A similar method of using the luminous energy, actually, is locating. Optical locators

were created as a result on the base of quantum electronics.

It is known that entire range of the electromagnetic vibrations conditionally can be divided into two parts, the boundary between which passes at the frequency of 300 GHz (λ=1 mm). The frequencies of lower than this boundary relate to the region of radio frequencies, into above - to optical range and occupy sufficiently wide section. However, for purposes location (especially in the atmospheric boundary layers) not all optical frequencies can be used as working due to the considerable absorption by the atmosphere. The absorption of luminous energy at different frequencies is different. The sections of frequency range with the smallest absorption are called the windows of transparency. They are most suitable for the work of locators. In the atmospheric boundary layers there are two pronounced windows from 0.33 to 0.75 μm and from 8 to 13 μm. In these ranges through the atmosphere it passes from 60 to 90% of luminous energy. Within the sections of range indicated spectral characteristic proves to be also strongly cut, and this fact forces very seriously to approach a question of the selection of operating frequency.

Tendency toward the use of an optical range is explained by several reasons. First, it considerably (into millions of times) is more "frequency-consuming" in comparison with the radio-frequency range. Thanks to this property in the optical locators it is possibl

to realize more broadband modulation than in radars. In the second place, use of the optical range makes it possible to obtain highly-directional radiations/emissions with comparatively low geometric dimensions of antenna systems, and to also improve almost all technical characteristics of the locators: angular resolution and range, accuracy of the measurement of coordinates, freedom from interference, etc.

Let us give several examples, which characterize optical locators. Their theoretical angular resolution is 10[illegible] times higher than in radars of microwave range. True, the laser technique of present time thus far yet does not make it possible to completely realize the theoretical possibilities of this high resolution; however, this problem, apparently, will be solved in the near future.

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For the equally probable detection of targets, which are located on equidistances and having radar cross sections, the required power of the transmitter of optical locator several orders of less than the power of the locator of microwave range. The confirmation indicated is correct when both of them have identical radiation patterns in the modes of receiving and radiation, the bandwidth of receivers and the effectiveness of detectors. In particular, optical locator

confidently detects object at the assigned range (if are satisfied the conditions stipulated above) at the power of transmitter 10' times of less than in RLS of millimeter range.

Laser locators are almost immune to the effect of the intentional interferences. These interferences can be of influence only in such a case, when their source will be located in the ray/beam of locator. However, taking into account that the ray/beam is very narrow (its width does not exceed several ten seconds of arc), the probability of the determination of the source of interferences in the ray/beam of locator is very low. The effectiveness of the action of the intentional interferences descends also as a result of applying of filters and lasers.

Optical locators, having extremely high technical characteristics, are at the same time characterized by light weight and overall sizes. In radars, as is known, this question is very problematic and is solved by compromise path.

The use/application of an optical range for purposes of location almost completely solves the problem of electromagnetic compatibility. A large quantity of locators, which are located in immediate proximity of each other, can work simultaneously, without creating interferences.

Together with the noted advantages, laser locators have a number of deficiencies/lacks. To the bases of them should be related the high attenuation of laser radiation/emission with the fog, the rain and the snow, that limits the range. In connection with this laser locators are most promising in outer space, where there is no atmosphere. They can find however and already has been found wide application under the conditions of the atmosphere for the solution of separate problems in the complex with RLS, when the long range of action is not required of the laser locator.

In their structure, principles of construction and fulfilled functions optical locators are almost completely analogous to the locating stations of radio-frequency range. With their aid are determined the same parameters of the object detected: range, height/altitude, angular coordinates and speed of motion.

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In optical locators are included the antenna system, transmitter, receiver, synchronizing unit, block of data processing and indicator.

Antenna is usual telescope. In the receiving circuit it is

supplemented by light filter. The use/application of a filter makes it possible to carry out reception of signals in the very narrow band and to exclude the possibility of the effect of the background interferences, created by solar radiation, the Moons, stars and other celestial bodies. Are presented hypotheses about the fact that in the near future will become possible the use/application of more complicated antenna systems, for example antennas of the type of the phased grating, which at present have already been utilized in the locating stations of radio-frequency range.

The fundamental requirements, presented to the antenna systems of optical locators, are analogous to requirements for the antennas of RLS of the usual type, i.e., those, etc. must provide high factor of amplification, assigned form of ray/beam, large zone of the survey/coverage of space for the smallest possible time interval, etc.

Transmitter consists of the generator of electromagnetic energy, as which is utilized the laser, pump oscillator, which excites laser, and modulator.

Receiver consists of two parts: optical and electrical. With the aid of the optical part, which consists of the antenna and the filter, recover and are filtered the light impulses/momenta/pulses,

reflected from the objects. Fundamental designation/purpose of electrics - transformation of the taken light impulses/momenta/pulses in the signals of video frequency and their amplification to the necessary level.

Synchronizing unit just as the synchronizer of radar, develops the impulses/momenta/pulses of the beginning of reading and synchronous starting/launching of transmitter and scanning/sweep of indicator. The block of mining the data serves for ranging to the object and parameters of its motion.

Based on the example of the generalized block diagram, shown in Fig. 16, let us explain the operating principle of the optical locator of ranging.

The generator of transmitter is carried out on the laser. It is excited by special pump oscillator, whose starting/launching is realized by impulses/momenta/pulses of synchronizer. The luminous flux (sounding pulses) of laser, after passing the system of lenses 1, called collimator, and lock 2 they are emitted into the space. Collimator forms/shapes the assigned radiation pattern, i.e., the divergence of ray/beam, and lock provides the required squareness of transmitted pulses. The emitted by laser luminous flux, after achieving object, is reflected from it and returns to the place of

radiation/emission.

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Here it is trapped by receiving antenna and through the light filter with the very narrow passband enters the photomultiplier, which fulfills the functions of detector. The detected signal after amplification on the video frequency is supplied into the block of data processing. The part of the energy of sounding pulse here is branched/shunted.

In the block of data processing is a special sensor, which develops the impulses/momenta/pulses through the strictly defined time interval. It is started by the branched signal, and it is turned off/disconnected by that accepted. By calculating the quantity of impulses/momenta/pulses, manufactured by sensor, is determined time t, spent on the passage of electromagnetic energy to the object and vice versa. As in the radar, on the known ones of time t and velocity of propagation of energy c is designed range to the discovered object. Data about the range, and also the sounding and echo pulses are supplied to the indicator for the visual observation.

Fig. 17 shows the block diagram of the optical radio tracking unit of the observed objects. On it the electro-optical part of the

station and the elements/cells, which fulfill the functions of accompaniment, are depicted in essence. Remaining devices/equipment in the figure are not shown, since they are analogous to the same devices/equipment of the locator of ranging, and the principle of their operation was already examined. In the radio tracking unit the luminous flux of laser is modulated according to the sinusoidal law, and from the output ot modulator, through collimator 1 and system of mirrors A and B it falls on mobile (receiving-transmitting) flat/plane mirror.

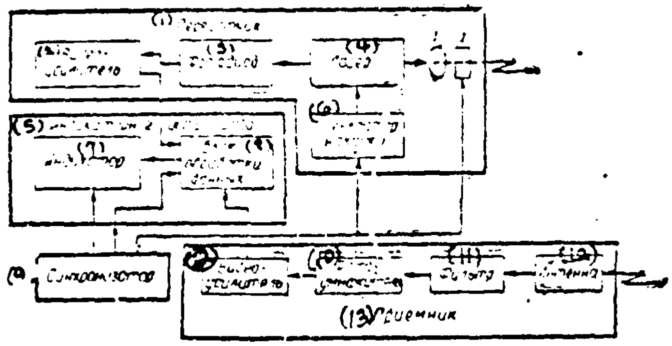

Fig. 16. Generalized block diagram of optical locator.

Key: (1). Transmitter. (2). Video amplifier. (3). Photodiode. (4). Laser. (5). Display unit. (6). Generator of pumping. (7). Indicator. (8). Block of data processing. (9). Synchronizer. (10). Photomultiplier. (11). Filter. (12). Antenna. (13). Receiver.

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The energy emitted into the space, after meeting on its path object, is reflected from it and again it falls on mobile mirror. The signal echo from the object is directed by this mirror to parabolic reflector C and is focused by it to the semitransparent mirror Д, which is called smasher. Smasher divides ray/beam into two parts: one part through the narrow-band filter is passed to the photomultiplier of the block of data processing for ranging, and another - through the same filter to the dissector - the device/equipment, which

develops the signals of angular errors. If the echo signal enters the center of dissector tube, then it exerts no effect on the servosystem. When image is displaced relative to center, in the dissector device/equipment are formed/shaped the unsymmetric pairs of the impulses/momenta/pulses, from which are developed the signals of angular errors. These signals are supplied to the servomechanism of servo system and are utilized for the automatic rotation of mirror (accompaniment of the observed object).

With the aid of the optical locators it is possible to measure the speeds of objects. The operating principle of such locators is based on the use of the Doppler effect. In this case they work in the mode of continuous radiation/emission. The proportional dependence of Doppler frequency and speed of motion makes it possible to graduate the scale of the display unit of the locator directly in units of velocity measurement.

Let us examine the most characteristic elements/cells, utilized in the optical locators.

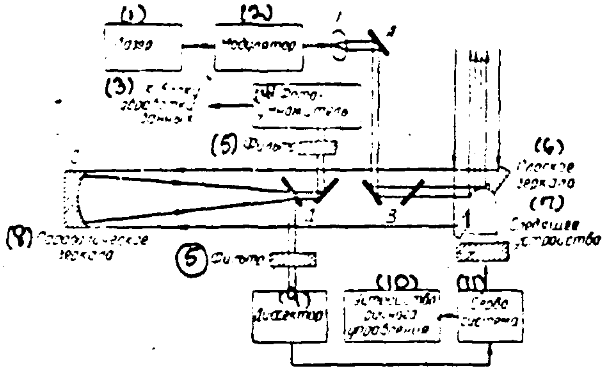

Fig. 17. Block diagram of optical radio tracking unit.

Key: (1). Laser. (2). Modulator. (3). To block of data processing. (4). Photomultiplier. (5). Filter. (6). Flat/plane of mirror. (7). Follower. (8). Parabolic reflector. (9). Dissector. (10). Devices/equipment of manual control. (11). Servosystem.

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Lasers. The physical bases of the work of lasers obey the law of quantum electronics. It is known from the course of physics that during irradiation of some solid or gaseous substances by wave particles - quanta of light (photons) - their atoms and ions pass from the ground level to the higher. The atom (ion), which passed to the higher energy level, proves to be in the excited state. Under specific conditions it can give up stored energy in the form of electromagnetic or thermal radiation/emission.

The transition/junction of atoms (ions) occurs spontaneously (spontaneously) or under the effect of environmental factors. Spontaneous transition/junction of one energy state to another is accompanied by noncoherent radiation of energy. This means that the radiations/emissions of different atoms occur at different moments of time over a wide range of frequencies. The transition/junction of atoms from one energy level to another under the effect of external electromagnetic field is called induced. The induced transitions/junctions are accompanied by the coherent radiation/emission of energy, i.e., by the synchronous (simultaneous) radiation/emission of many atoms in the very narrow frequency band. The excitation of the active material of laser occurs due to the energy of the special source, which is called pump oscillator.

Depending on the form of active material the lasers are classed to the solid-state ones, the semiconductor ones, the gas ones, the plastic ones and the liquid ones. Solid-state lasers are divided into two forms: crystal and glass.

Solid-state ruby laser emits coherent oscillations with a wavelength of 6943 Å. If excitation energy is insufficient, then radiation/emission is incoherent and occurs on the dahlin of waves

6943 and 6929 Å. Structurally ruby laser is fulfilled in the form of the rod, whose ends/faces are polished. One of them is covered with the dense layer of silver and it is absolutely opaque (its coefficient of transmission it is equal to zero). The second, although it is plated with silver, its coefficient of transmission is different from zero (about 10%). This end/face is called semitransparent.

The polished ends/faces of ruby rod are mirrors with strictly bussing arrangement, and this is the fundamental condition for the realization of resonance system. Thus, as resonance system in the ruby laser serves rod itself. As a result of multiple reflections from the mirror ends/faces of rod and interaction with the active material the oscillations/vibrations are amplified and emerge from laser in the form of the avalanche-type flow through the semitransparent end/face.

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In this case only the oscillations/vibrations with a wavelength of 6943 Å, which are propagated in parallel to the longitudinal axis of rod are amplified. All remaining oscillations/vibrations are suppressed by resonance system as a result of the short time of their interaction with the active material.

Glass lasers are made on the base of glass active medium with the admixture/impurity of some rare-earth elements. Their fundamental advantages in comparison with the ruby lasers - lower threshold of excitation and the possibility of the generation of powerful/thick output pulses. They can be prepared in the form of the filaments, whose diameter is commensurated with the wavelength.

The principle of the work of the lasers, made on the base of semiconductor active medium, consists of the following. In the crystals of semiconductors the electrons occupy one of energy bands, which is called valence. if we report supplementary energy to electron, then it will pass into the zone of conductivity (with the higher energy). As a result of transition/junction is formed the pair of charge carriers: electron and hole. Under specific conditions the excited electrons pass from conduction band into the valence band, and holes at this time complete transition/junction in the opposite direction. As a result of such transitions/junctions occurs the recombination of pairs electron-hole, which is accompanied by release of energy in the form of the quanta of luminous radiation (photons).

The phenomenon of the recombination of pairs electron-hole and, consequently, also recombination radiations/emissions are observed in

the p-n junctions of some semiconductor materials in transit through them of forward current. The most intense radiations/emissions are observed in the p-n junctions from arsenide of gallium, antimonous indium, alloys of germanium with the silicon and carbide of silicon. With a sufficient concentration of the excited electrons, which are located in conduction band, the spontaneous radiation/emission passes into that induced; semiconductor laser begins to generate in this case.

Resonance system in the semiconductor laser, just as in the ruby, is formed by the mirror-polished faces of semiconductor crystal. In order to ensure directional radiation of light/world, crystal face they must have strictly bussing arrangement according to the relation to each other and perpendicular - relative to plane of p-n junction. Semiconductor lasers are characterized by the high efficiency (it it can exceed 50%), low sizes/dimensions and large radiated power. They are capable of working in continuous and pulse modes.

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Wave band, generated by semiconductor lasers, depends on composition and percentage of the elements/cells, entering the active material. For example, in the semiconductor, prepared from

arsenide-phosphide of gallium with different percentage relationships/ratios of elements/cells, generation can be obtained in the range from 6100 to 8000 Å, and in the compound gallium arsenide-indium - in even the wider region f·om 6500 to 31000 Å.

In the gas lasers as the active medium is utilized or one gas (helium, neon, argon, krypton, xenon), or mixture of two and even three gases. The major advantages of gas lasers in comparison with others it consists in the fact that they emit in the very narrow frequency band, i.e., possess the high degree of coherence.

Plastic lasers are structurally the twisted in the form of spiral optical filament, placed into the Dewar container filled with liquid nitrogen. They emit the impulses/momenta/pulses of visible light with a wavelength of 6130±7.5 Å.

The possibility of applying the liquids as the active media of lasers at present is investigated. Such media can be liquid hydrogen, organic and other liquids. it is assumed that the manufacture of liquid lasers will cost less. With their aid it will be possible to generate powerful/thick radiations/emissions with the simple retuning in the frequency.

Pump oscillators. In laser generator independent of its type is

included the special device/equipment, called pump oscillator, which serves for exciting the active material of laser. Fundamental designation/purpose of the device/equipment of excitation - effective transformation of electrical energy into the light with the assigned frequency. The highest effectiveness of transformation is obtained, when the radiations/emissions of pump oscillator are focused on the active material of laser and they are maximally absorbed by it.

In the solid-state lasers, for example, gas-discharge tube, which winds the rod of active substance by spiral can serve as pump oscillator. However, such pump oscillators have low effectiveness, since the very large part of the energy, emitted by tube, is scattered to the sides and does not fall on active material.

The considerably higher effectiveness has pump oscillator, which consists of the elliptical reflector and the gas-discharge tube. The luminous energy, emitted by tube, almost completely is focused to the active material and only small part of it is scattered to the sides. The use/application of an elliptical reflector makes it possible to decrease the energy, consumed by pump oscillator, approximately/exemplarily 10 times in comparison with the energy, which is consumed by pump oscillator in the form of spiral gas-discharge tube.

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There are other principles of the construction of pump oscillators, which make it possible even to more raise the effectiveness of energy conversion.

The excitation of the active medium of semiconductor lasers is realized not by light, but electrical pumping. Pumping gas lasers can be conducted by high-frequency electromagnetic field or direct current, and plastic - by pulse ultraviolet radiation.

Modulators. The radiation/emission of laser locator must be modulated for obtaining the information about the observed objects. Are at present applied amplitude, frequency and phase modulation, and also modulation of the luminous flux by a change in the polarization. The type of modulation is selected on the basis of the requirements, presented to the locator. The modulators of laser radiations/emissions must possess broad-band character and linear modulation characteristic.

Amplitude modulation is realized by changing the Q of the resonator of laser. Therefore it is occasionally referred to as Q-modulation. Fig. 18 shows the method of control of Q with the use/application of the rotating reflector, as which can be used, for

example, the prism with total internal reflection. With this method of control the Q will be high only at that moment/torque, when reflector proves to be with the high degree of accuracy it is parallel to mirror. If the speed of rotation of reflector is brought to 20000-30000 r/min, then it is possible shaped pulse by duration about 0.1 μs.

For the control of the quality of resonator with Q-modulation wide application obtained also different electro- and magneto-optical locks. They are placed between the mirror ends/faces of laser rod. The lock is closed during the larger part of the time of action of pump oscillator, and energy of light/world cannot pass from one end/face of laser to another. At this time generation conditions prove to be disrupted, and the accumulation of energy occurs as a result of the transition/junction of the larger part of the atoms of active material to the higher energy level.

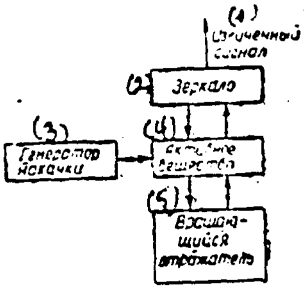

Fig. 18. Amplitude modulation with the aid of the rotating reflector.

Key: (1). Emitted signal. (2). Mirror. (3). Pump oscillator. (4). Active substance. (5). Rotating reflector.

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Then lock rapidly is opened/disclosed, light/world almost instantly reaches mirror and as a result of avalanche multiple reflection in the laser is established/installed the generation.

There are other methods of amplitude modulation, for example by a change in the mode/conditions of the work of pump oscillator, and also with the use of the Faraday, Kerr and Pockels effects.

Frequency modulation is based on interaction of electrical or magnetic field with the active material of laser. The effect of electric field E causes splitting/fission of energy levels, in

consequence of which appears a discrete/digital change in the frequency of the emitted by laser to value Δf, for example for the ruby laser $\Delta f=5.29\cdot10^{4}\cdot E$. Thus, changing electric intensity, it is possible to modulate light laser emission in the frequency.

Modulation of laser radiation/emission by magnetic field is analogous to modulation by a change in the electric field. The value of a change in the discrete/digital frequency is determined by the expression

$$\Delta f=\frac{1}{4\pi}\cdot\frac{e}{m}H,$$

where e - electron charge, m - mass of electron.

Both forms of modulation have a number of the identical deficiencies/lacks, to the bases from which relate low efficiency, a discrete/digital change in the frequency and the difficulty of designing of effective pumping.

The receivers of optical locators (by analogy with RLS) are divided into the detector ones (straight amplification) and the superheterodyne ones. Straight receivers, having the wide passband of frequencies, which is determined, actually, by the passband of optical filter, they possess a comparatively low freedom from interference. They together with the useful signals accept all background interferences, whose spectrum is located in the band of

filter. In this their deficiency/lack. Superheterodyne receivers have comparatively narrow band (it is determined in by the normal band of the transmission of radio engineering circuits) and differ by the increased freedom from interference.

The sensitivity of superheterodyne type receivers, determined by the minimum power, at which they react, is found from expression $P_{мин} = (h \cdot f \cdot \Delta f)/q$, where h - Planck's constant, f - emission frequency of laser, Δf - passband of receiver and q - quantum effectiveness. They are considered as the more promising. However, in connection with the specific difficulties, which appear during their technical realization, straight receivers at present more frequently are applied.

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Lasers and detectors are the most important elements/cells of optical receivers.

Optical lasers can be made with the use/application of principle of the traveling wave or in the form of amplifier with the cavity resonator. Their fundamental designation/purpose - amplification of the signals of laser radiation/emission and the guarantee of the assigned selectivity, and also the decrease of receiver noise and the

suppression of extraneous interferences. The factor of amplification of laser, as a rule, does not exceed four times, which corresponds to 6 dB. However, for the effective indication of the objects detected the signal is required to enforce according to the power into 10^3-10^4, which corresponds K_p =30-60 to dB. In order to obtain this value K_p, traveling-wave amplifiers are collected into the sections, which consist of 7-10 cascades/stages. Each amplifier stage of section is divided with the unidirectional insulator, which obtained the designation of gyrator. The use/application of a gyrator considerably decreases the probability of exciting the amplifier.

Fundamental advantage of lasers - very high selectivity. They amplify only those signals, whose frequencies are equal to the natural frequency of amplifier or are very close, i.e., they have very high selectivity.

The detectors of optical straight receivers fulfill two functions - is converted optical signal into the electrical and they realize a demodulation of the signal accepted. The type of detector in essence determines diagram and construction/design of receiver. As the detectors are applied the photomultipliers, photo-LBV and different semiconductor devices, which use phenomena of photoconductivity. Depending on the type of the utilized detector straight receivers are divided into thermal and photoelectric.

In the thermal receivers as the detectors more frequently are applied the bolometers, thermistors and thermocouples. Most sensitive of them - bolometers and thermocouples. The frequency band, in which can work thermal receivers, is very wide; for some types of detectors it stretches up to the radio frequencies. Main disadvantage in all thermal receivers - large inertness.

The detectors with the external and internal photoeffect are utilized in the photoelectric receivers. To the detectors with photoemissive effect relate electrostatic photomultipliers, dynamic photomultipliers with the lattice-type fields, broadband vacuum photocells, photo-klystrons and photo-LBV.

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Electrostatic photomultipliers permit implemention of reception of the signals, modulated by frequencies from 100 to 200 MHz. They have high sensitivity, high factor of amplification and uniform response. Dynamic photomultipliers with the lattice-type fields have a multiplication factor of approximately 10^5 in the passband of frequencies of approximately 1 GHz. Broadband vacuum photocells detect the signals, modulated by frequencies to 10,000 MHz, and

photo-klystrons - to 8-13 GHz. Photo-LBV, which possess large broad-band character, are considered most promising photo detectors. They pick up signal, modulated by the frequencies of meter and decimeter wave bands.

To detectors with the internal photoeffect relate semiconductor photodiodes, photoresistors, photoparametric detectors and detectors with the photoelectromagnetic effect.

Semiconductor photodiodes are characterized by high sensitivity, large efficiency and rapid response.

High sensitivity and rapid response are characteristic for the photoresistors. Their ultimate sensitivity reaches 10^{-10}-10^{-12} W, and time constant - 10^{-6}-10^{-7} s. Photoresistors, furthermore, do not go out of order under the influence of very considerable power.

Photo-parametric detectors are characterized by high sensitivity, high factor of amplification, by broad-band character and low noise factor. Fundamental special feature/peculiarity of photo-parametric detector - ability not only to demodulate the signals accepted, but also to realize their amplification.

Detectors with the photoelectromagnetic effect in contrast to

all other detectors with the internal photoeffect work without the secondary stress of bias/displacement, and in this their major advantage.

In superheterodyne type receivers additionally are included the mixer and heterodyne, with the aid of which is realized the frequency conversion of optical range into the intermediate frequency of radio engineering range. As the mixers can be utilized vacuum photomultipliers, photo-LBV, photodiodes and photoresistors. Most frequently the mixers are fulfilled with the use/application of photomultipliers, since they possess the considerably greater internal resistor/resistance in comparison with other elements/cells of analogous designation/purpose and therefore they can work at the low power of heterodyne in the range of the frequencies of 100-200 MHz. Their main disadvantage - low quantum effectiveness.

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